Chapter VIII- Existing Quality and Sources of Degradation

Prepared by

J Robert Owen

for:

Animas River Stakeholders Group

December 2000

JAN - 2 2001

Ref:8TMS-L

MEMORANDUM

SUBJECT: Sample Disposal - Animas 38

FROM: Gregory J. Saunders, Environmental Scientist
Laboratory Services Program

TO: Carol Russell, Project Manager
8EPR-EP

Please advise regarding disposal of the samples collected at the Animas River site in September 12 and 27 of 2000. The data package was sent for your review on Dec. 6 and unless requested otherwise, the samples will be disposed on or about Feb 1, 2001.

Space limitations require that timely disposal of samples be accomplished using defined procedures. In addition any samples exceeding analytical holding times will be disposed as appropriate.

The Laboratory's policy is not to run or rerun samples that have exceeded holding times see Memorandum dated Oct 24, 1995, signed by Mel McCottry, Lab Director and Tony Medrano, Quality Assurance Director entitled "Acceptance of Samples for Analyses".

Please advise by Monday, January 22, 2001, whether or not the samples collected at the above site fall 2000, can be disposed of by **signing this statement of your decision and return it to the lab.** This verifies and confirms your receipt of the data package.

If retention of samples is required, please provide the following information:

EPA sample tag number(s)______________________________

Justification for retention of sample(s) __________________________

Expected date of release for disposal __________________________
(Default date is when analytical holding times have expired)
(Samples held for litigation will not be held in cold storage beyond holding times)

For approval of sample disposal:

Please sign and date:____

Return to : Gregory J. Saunders, Environmental Scientist
Laboratory Services Program, 8TMS-L Fax:(303)312-7800
Jill Smits, Sample Custodian 303-312-7770

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Acronyms

Trace metals	
Ag	Silver
Al	Aluminum
As	Arsenic
Cd	Cadmium
Cu	Copper
Cr	Chromium
Hg	Mercury
Ni	Nickel
Pb	Lead
Fe	Iron
Mn	Manganese
Sb	Antimony
Th	Thallium
Vn	Vanadium
Zn	Zinc
Major Cations	
Ca	Calcium
K	Potassium
Mg	Magnesium
Na	Sodium
SiO	Silica
Major anions	
CO3	Carbonate
HCO3	Bicarbonate
NH3	Ammonia
SO4	Sulfate
DO	Dissolved oxygen
pH	Measure of acidity/basicity
Units of measure	
cfs	Cubic feet per second (28.32 l/s)
l/s	Liters per second
mg/l	Milligrams per liter (ppm)
υg/l	Micrograms per liter (ppb)
BDL	Below limit of detection
TVS	Table value standard
WQS	Water qualtiy standard

Organizations and Agencies

ARSG	Animas River Stakeholder Group
CDPHE	Colorado Department Public Health and Environment
EPA	U S Environmental Protection Agency
DMG	Colorado Division of Minerals and Geology
BLM	U S Bureau of Land Management
SGC	Sunnyside Gold Corporation
USFS	U S Forest Service
USGS	U S Geological Survey
WQCC	Colorado Water Quality Control Commission
WQCD	Colorado Water Quality Control Division

Other

AT	American Tunnel
UAA	Use Attainability Analysis
WQRM	Water quality regression method

CHAPTER VIII - EXISTING WATER QUALITY AND SOURCES OF DEGRADATION

The hearing in 1994 changed many water quality standards for the Animas River basin. The changes, based on data collected between 1989 and 1994, reassessed the status of aquatic life and estimated the potential for establishing aquatic life in the Animas River and several of its tributaries. Since 1994, several activities affecting water quality have occurred and a substantial amount of new data has been collected. New data is used to

- quantify seasonal and annual variations in loading from identifiable mining related sources,
- improve estimates of metal contributions from all other sources,
- evaluate seasonal variations in water quality at the four gaging stations, and
- evaluate the effect recent remediation projects have had on the chemistry of Mineral Creek, Cement Creek, and the Animas River.

Water quality goals that may reasonably be achieved through restoration of disturbed sites is evaluated at the end of this chapter and in Chapter XI using the new data together with the data from earlier studies. Alternative uses and standards that might be achieved through remediation are proposed in Chapter XII.

The UAA focuses on stream segments with aquatic life classifications and standards disapproved by EPA in their letter of September 1998 and/or are contained in the state's 1998 303(d) list. These stream segments are shown in Table 8.1

Table 8.1 Stream Segments Shown on CDPHE 1998 303(d) list

Segment	Description	Use Impaired	Constituent(s)
2	Animas above Eureka	Downstream aquatic life	Al, Cd, Cu, Fe, Pb
3a	Animas Eureka to Cement Ck	Aquatic life	Zn*
3b	Animas, Cement Ck to Mineral Ck	Downstream aquatic life	Al, Cd, Cu, Fe, Pb
4a	Animas, Mineral Ck to Elk Ck	Aquatic life	pH, Cu, Fe, Zn*
4b	Animas, Elk Creek to Junction Ck	Aquatic life	Zn
7	Cement Creek	Downstream aquatic life	Al, Cd, Cu, Fe, Pb
8	Mineral Creek above So. Mineral	Downstream aquatic life	Al, Cd, Cu, Fe, Pb
9b	Mineral, So. Mineral to Animas	Aquatic life	pH, Cu*, Fe*, Zn

* Standards disapproved by EPA on August 27, 1998.

EVALUATING EXISTING WATER QUALITY

Chemical and physical water analyses were done at several hundred sites within the basin. Measures were obtained for ten different physical properties (discharge, pH, hardness, etc); five major cations; seven major anions; four nutrient species and twenty-eight different metals since comprehensive studies began in 1991. Total recoverable and dissolved (.45 micron filter) fractions were analyzed for most metals. All data are contained in **Appendix 8 A**.

The purpose of this section is to evaluate and compare current (1997-1999) stream water quality with table value standards (TVS) used by the Colorado WQCC for adopted or proposed uses. The principal emphasis is on the aquatic life classification, however, waters classified for water supply or agriculture are discussed where appropriate. Constituents exceeding mandatory drinking water limits (MDL's) are discussed as potential human health concerns. This section emphasizes selected sites on main stems and tributaries where data are available to characterize temporal variations in water quality. Data collected from October 1, 1996 through 1999 are compared to earlier data. This period was chosen to insure that the most recent data was used, and follows implementation of the Sunnyside Gold Corporation (SGC) consent decree. The latter is important because several remediation projects have improved water quality in some segments since the standards were revised in 1995.

Colorado's "Basic Standards and Methodologies" (5CCR 1002-31) applies aquatic life standards for fifteen different metals, pH, dissolved oxygen (DO), residual chlorine, unionized ammonia (NH3), cyanide, and sulfide. DO, residual chlorine, and NH_3 are associated with domestic or municipal wastewater, which has a negligible effect on waters in the Upper Animas Basin. DO and NH3 are well within established criteria for all current use classifications and are only briefly mentioned in the UAA. Residual chlorine is usually not measured in streams and rivers. Data for DO and NH3 are available for the Animas River below Silverton, at A72, prior to 1994 and a few sites above A72.

Cyanide, associated with some mining activities, was sampled as a part of the UAA. One cyanide sample exceeded the limit of detection. Hydrogen sulfide, usually associated with decaying organic matter, was not sampled for the UAA.

Standards for aquatic life are established for Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Hg, Ni, Se, Ag, Th, and Zn. These metals are evaluated depending on the type of past and present wastes that could have been discharged to streams in the area or the type of regional geology. All studies have shown that Cr, Ni, and Se are extremely rare in the basin. The occurrence of Ag, As, and Hg are also rare, and where found they are usually only in the immediate vicinity of mine openings (WQCD. 1994).

Water quality standards are also adopted for water supply and agricultural if the uses are present or have the potential to be used. Additional inorganic and metal parameters that were evaluated for these uses include Fe, Mn, fluoride (F), boron (B), chloride (Cl), sulfate (SO4), nitrite+nitrate (NO2+NO3), antimony (Sb), and beryllium (Be). Except for Fe, Mn, and SO4, these parameters were rarely found, and if they were present, concentrations were well below criteria for water supply and agricultural uses.

Fe (dis), Mn, and SO4 exceed water supply criteria throughout the Upper Animas Basin. The only segment discussed in this chapter with a water supply classification is the Animas River between Elk Creek and Junction Creek (segment 4b). A few localized area (i.e. adits, springs, and seeps) have concentrations of As, Cd, Cu, Pb, and Zn that exceed water supply criteria, however they are remote from permanently inhabited areas. As, Cd, and Pb have human health criteria. Other metals with human health criteria, Ag, Be, Cr, Ni, Hg, Sb, and Th are rare and if present have concentrations well below criteria levels. Ba is common in the basin but concentrations are well below the criteria established for human health.

The most common constituents exceeding agricultural criteria are Cu and Mn. Cu and Mn criteria, both 200 ug/l, apply to sensitive irrigated crops. The Animas or its tributaries are not used for irrigation until the river exits the canyon about 27 miles downstream from Silverton (segments 4b, 5a, and 5b). Localized areas near several draining adits, springs or seeps, have levels of As, Cd, Pb, or Zn that could be harmful to animals watered from those sources.

Appendix 8A includes analyses for major cations (Ca, K, Mg, SiO, Na) and anions (CO3 and HCO3). Trace metal analyses for Sb, Vn, and Th were later requested by the EPA. These metals were rarely detected (Farrell, 1997).

Waters in the basin were also screened for standard organic and pesticide residues. Trichlorethene, toluene, 2-hexanone, 1,1,2,2,-tetrachloroethane, and dieldrin were detected at low concentrations at one or more locations in the main stem of the Animas or its tributaries. None of the detected values exceeded aquatic life or human health criteria (Farrell, 1997).

Al, Cd, Cu, Pb, Fe, Mn, and Zn are the metals that most affect water quality in the basin, and are the focus of the UAA. Their concentrations are high, both as total recoverable and dissolved, in different parts of the basin.

Procedures for evaluating water quality and establishing standards are determined by the Colorado WQCC ("The Basic Standards and Methodologies for Surface Water" 5CCR 1002-31). Existing or ambient water quality[1] is compared to TVS. The regulation defines ambient quality as percentiles of representative data. The 85th percentile is used for the dissolved metals; the 50th percentile is used for total recoverable Fe, and the 15th and 85th percentiles are used for pH. Only the lower or 15th percentile is used for pH in the UAA because of the acid conditions that occur in the basin. If ambient quality is better than TVS for the classified use, TVS are adopted. Numeric standards for aquatic life are usually based on chronic table value standards (TVS) and are considered protective of sensitive aquatic species. Aquatic life TVS for Cd, Cu, Pb, Mn, and Zn vary with water hardness. Higher metal concentrations are tolerated at higher hardness values. The practice of the WQCD is to compare 85th percentile concentrations to TVS calculated from median hardness for the segment (Susan McIntyre, personal communication).

[1] Ambient quality for most metals is determined from the dissolved fraction, which is the portion that passes through a 0.45 micron filter. Standards for Fe use the unfiltered fraction for aquatic life and the filtered fraction for water supply.

If natural or irreversible human-induced constituent concentrations are higher than the specified chronic TVS, but the classified use is present, ambient standards, 85^{th} percentile (50th percentile for trec Fe) may be adopted. The EPA rejected the WQCC's ambient standards for Zn for segments 3a, 4a, and 9b because there was no proof that high concentrations exceeding TVS for aquatic life were irreversible. EPA rejected ambient standards for Cu and Fe in 9b for the same reason.

The WQCC regulations also provide for site-specific water quality standards. This methodology may be based on either acute or chronic criteria, and may be used for aquatic life segments if factors other than water quality substantially limit the diversity and abundance of species present. Site-specific standards require a use attainability assessment (UAA) to support them. The WQCC used the site-specific approach for Zn in segment 4a, however, that standard was rejected by EPA because of the uncertainty of the method used to develop it.

Narrative standards (5CCR 1002-31.7 (1)) may be applied if numeric standards are inappropriate. This provision was used for segments 2, 3b, 7, and 8 owing to high natural levels of acid and metals that prevent attainment of aquatic life uses. Reduction of human-related sources from these segments, however, is critical to the achievement of goals in downstream segments. The WQCC adopted and the EPA approved narrative standards for segments 2, 3b, 7, and 8.

Methods for Data Analysis

Two methods were used to evaluate water quality. The first method is consistent with CDPHE practice. It compares the 85^{th} (50^{th} for trec Fe) percentile concentration to chronic TVS, utilizing median hardness for those constituents whose TVS are a function of hardness. The data and the calculations are in **Appendix 8B**.

The second method uses a water quality regression model (WQRM) to account for variations in solute concentration owing to flucculations in stream flow and season. Figure 8.1 illustrates the relationship between stream flow and hardness, Al, Cu, and Zn for A72, the Animas River below Silverton. Stream flow alone accounts for most of the variation in hardness and Al at this site. Most of the scatter in the Cu and Zn data can be attributed to stream flow and the time of the year the data was collected. These two factors account for most of the variation in solute concentration in surface water in the Upper Animas Basin.

The WQRM was used to estimate hardness and selected metal concentrations as a function of stream flow and time of the year. It was applied to main stem and tributary segments in the Upper Animas Basin that had sufficient temporal data. The WQRM was not used for solutes if more than 10 percent of the values were less than detection. The methodology is more fully described in **Appendix 8C**.

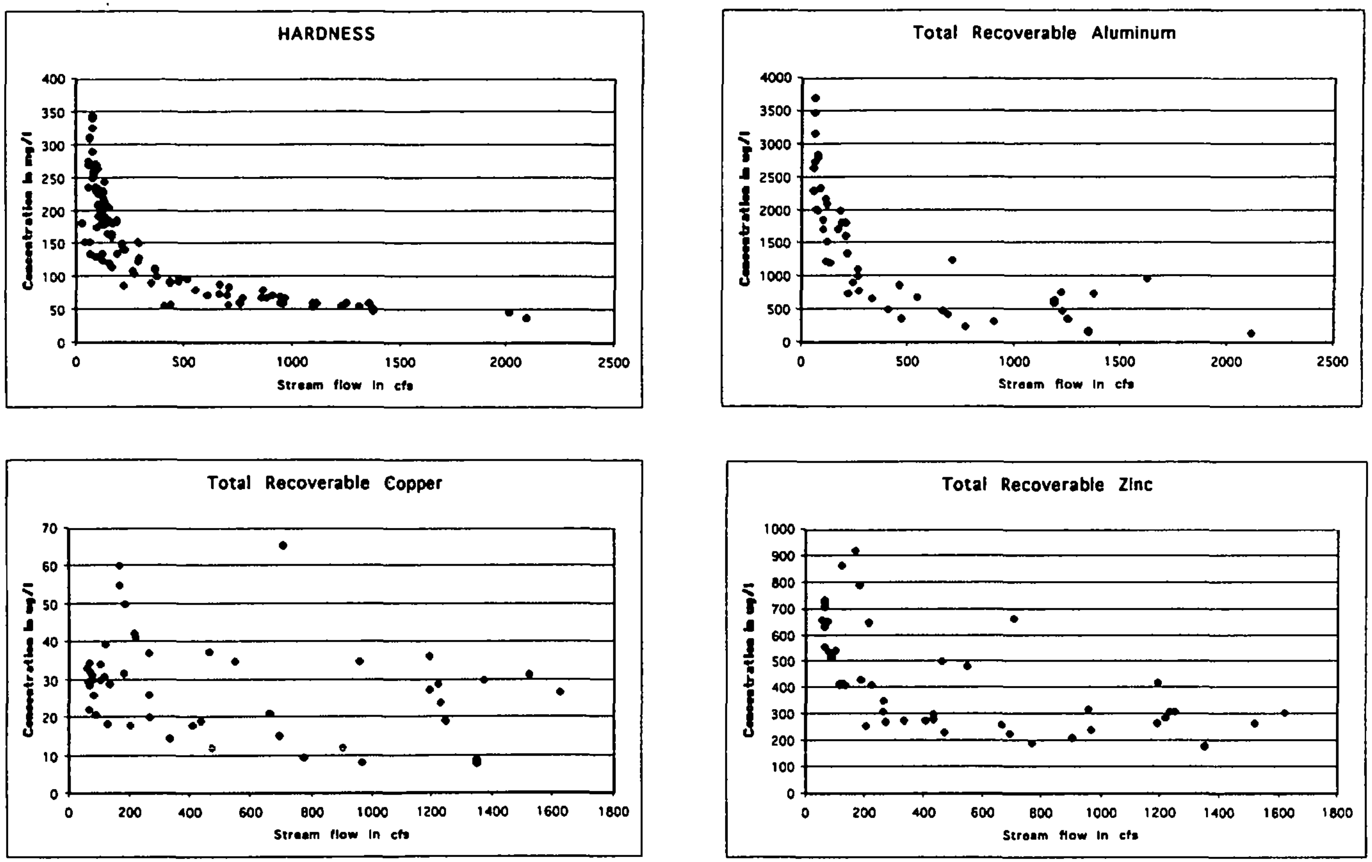


Figure 8.1 Relationship between stream flow and solute concentration for representative solutes in the Animas River below Silverton, A72

This WQRM method has two advantages. It provides a means for evaluating the effect of remediation on changing water quality, and it allows for identification of streamflow and time periods when concentrations are likely to critically affect aquatic life. Different implementation strategies may be needed depending on whether critical concentrations occur at high or low flow. Solute concentrations during the base flow period, usually November through March, are dominated by groundwater and adit related sources of solutes. Seasonal runoff from snowmelt and rainfall, and percolation of water through the soil mantle and mining waste piles affects the solute concentration during the rest of the year. High acid potential waste rock and the regional surface geology have the greatest effect on solute concentration in the Animas Basin during the runoff period.

Data Analysis

The regression methodology requires that concentration data be gathered over a wide range of flow conditions and throughout the year. Year-round monitoring at four gaging stations, Figure 8.2, began on October 1, 1993. These stations are generally sampled for water chemistry at least once a month. Several other stations on the Animas River, Cement Creek, and Mineral Creek were monitored monthly for chemistry and flow by the USGS during 1998 and 1999 to characterize intermediate points for selected reaches. The intermediate stations also establish baseline quality conditions that may be used to evaluate the effect of future remediation. Summary statistics, R^2, standard error, coefficient of variation, and numbers of observations are in **Appendix 8C**.

Tables 8.2 a-g compare the 85th percentile concentration found in the UAA segments from 1997 to 1999 to TVS criteria and to the water quality standards (WQS) adopted by the WQCC in 1995. Segments 2, 7, and 8 have narrative standards and no aquatic life classifications. Ambient conditions (85th percentile) that existed prior to 1997 are compared to water quality for the 1997 to 1999 period and no TVS are given for these segments. Constituents that are present, but whose concentrations exceed aquatic life, human health, or agricultural criteria less than 15% of the time are acknowledged in the text. It is presumed that these constituents meet all applicable WQS.

Hardness, as a function of stream flow, is used to compute TVS for Cd, Cu, Pb, Mn, and Zn. The variation in concentration of the target metals and hardness was standardized to the average monthly stream flow at the four gaging stations. Expected solute concentrations are compared to TVS as a function of stream flow and hardness. The results, shown graphically, were calculated using the WQRM.

Levels of Al, Cd, Cu, Fe, Mn, and Zn for the 1997 to 1999 period exceed the WQS on several segments. The WQS were developed from pre-1995 data. Higher concentrations found in the recent data are the result of more intensive monitoring during the winter base flow. The more recent data provides a better reflection of the operation of the hydro-chemical system in the basin, and is not due to degradation of water quality. Aluminum, which has proven to be an important water quality factor in the winter, was sampled only in the summer before 1995.

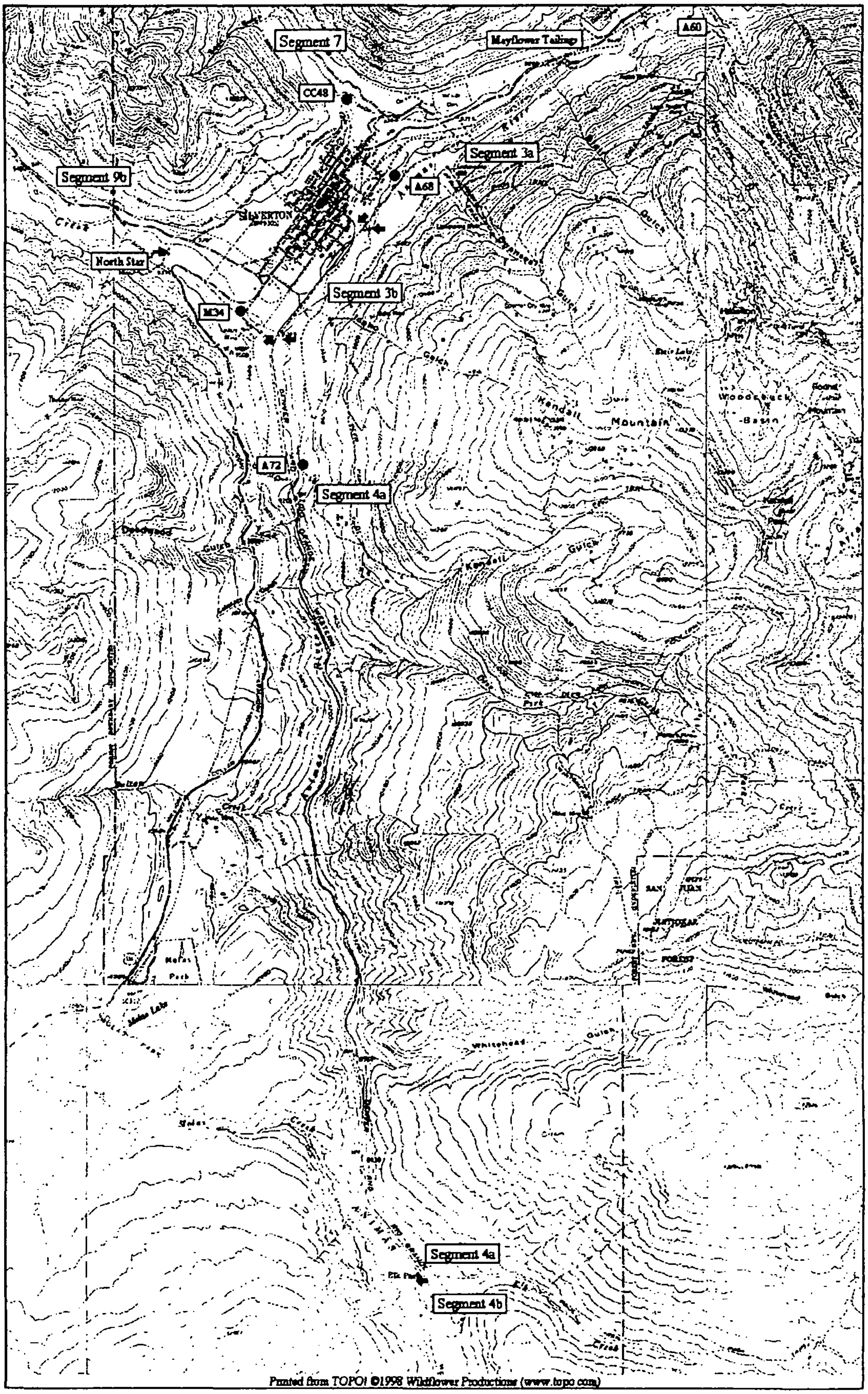


Figure 8.2 Principal gaging stations, A68, CC48, M34, and A72 used for water quality analysis in the upper Animas Basin

Segment 2

Segment 2 is the headwaters of the Animas River and extends to Maggie Gulch about two miles south of the Eureka town site Figure 8.3. Principal tributaries include California, Placer, Picayne, Burrows, Grouse, Burns, and Eureka Gulches. Over forty mine sites with waste rock or active drainage were sampled within the segment. Elevated levels of As, Ag, Cd, Cu, Pb and Zn are found in California, Burrows and Eureka Gulches near the Lucky Jack, Mountain Queen, Columbus, Silver Wing, Comet, London, and Vermillion mines.

Ore mills at Eureka introduced huge quantities of tailings (crushed ore) into the Animas River and onto its floodplain, principally between 1900 and 1930. This caused the channel to aggrade, which raised the base of the streambed by about one meter, since mining began (Vincent, 1999). The result of the aggradation was to obliterate the pre-mining morphology of the stream and destroy the willows that provided bank stability and riparian habitat (Vincent, 1999). Approximately 80% of these tailings have been swept downstream out of the Eureka-to-Howardsville reach (USGS, 2000), and incorporated into stream sediments. These tailings may be impacting water quality.

Most water quality data has been collected from A33, the Animas River above Eureka Gulch, located near the lower end of the segment. The USGS sampled A33 on 12 different dates in 1998-1999. Water quality generally remains unchanged since 1994, although some remediation has occurred in the headwaters of Segment 2. The 85th percentiles show differences in Cu and Zn between the older and more recent data, however, the data is insufficient to determine if this represents a true change in water quality. Cd, Cu, and Zn remain above chronic TVS for aquatic life. *The water quality data shown in Table 8.2a does not support the conclusion in the 303(d) list that the segment is impaired for Fe or Pb.*

Table 8.2a Ambient water quality, 1991-94 and 1997-99 in segment 2. Units are in micrograms per liter except pH (s.u.) and hardness (mg/l)

Site		Hard	PH	Al	Cd	Cu	Fe Trec	Fe Dis	Pb	Mn	Zn
	TVS					Not applicable					
	'91-'94	48	6.9	100	2.9	16	61	Bdl	Bdl	800	700
A33	'97-'99	64	6.5	87	2.9	30	64	Bdl	Bdl	780	550

Bdl=Below detection limits.

Aquatic life: Water quality data at A33 indicates the segment does not meet aquatic criteria for Al, Cd, Cu or Zn. No dissolved Ag, As, or Se were detected at A33. Occurrences of Cr, Ni, and Th were rare and well below aquatic life thresholds.

Human health: Drainage in the vicinity of the Lucky Jack, Columbus, and Vermillion mines and Burrows gulch exceed water supply MDL's for As, Cd, Pb, and Zn.

Agriculture: All agricultural criteria are met at A33, except Mn. Drainage near the Lucky Jack, Columbus, and Vermillion mines and Burrows gulch do not meet agricultural criteria for As, Cd, Pb, or Zn.

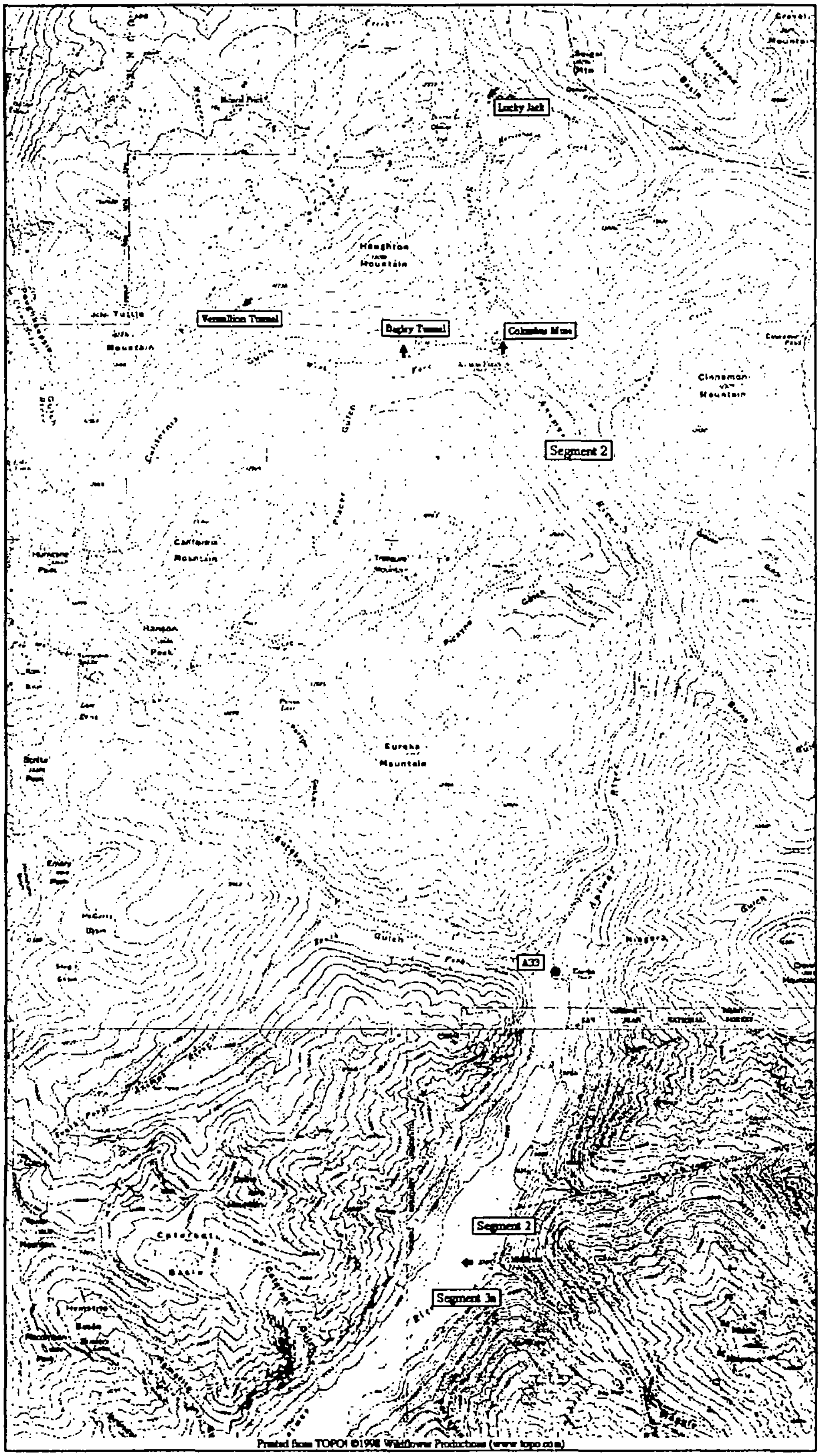
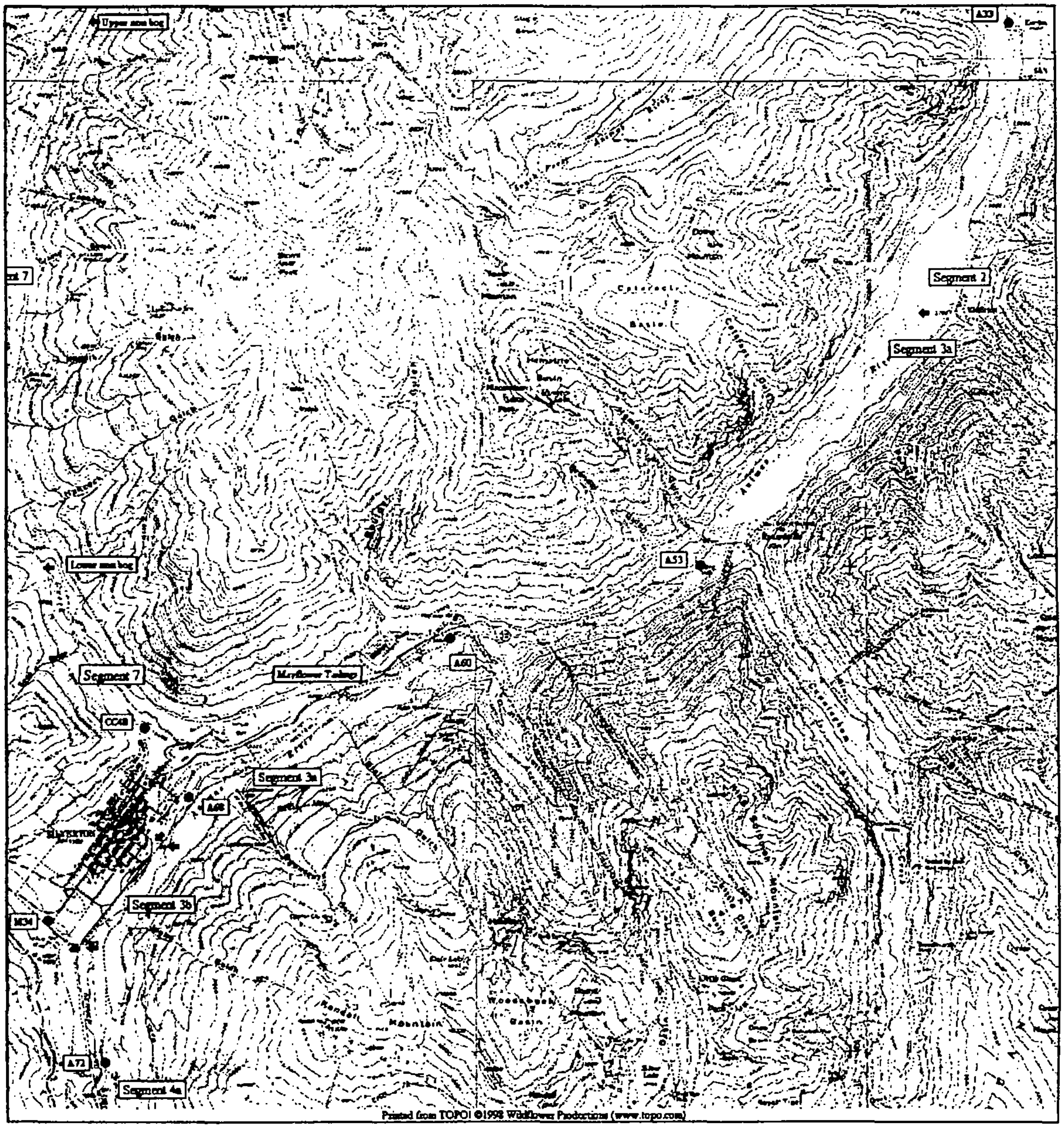


Figure 8.3 Boundaries of Segment 2 of the upper Animas Basin and selected monitoring loactions



Figurea 8.4 Boundaries of Segments 3a and 3b of the upper Animas Basin and selected monitoring locations

Segment 3a

This segment is the main stem of the Animas from Maggie Gulch to Cement Creek at Silverton, Figure 8.4. Investigations during the early 1990's and in 1998 showed that the segment supports several age classes of brook trout. Several large mines with drainages are present but are characterized by relatively low concentrations of metals and acidity. However, several mill sites and reclaimed mill tailings are located on terraces of the valley floor along the reach. Some mill tailings remain from circa 1930. SGC relocated some mill tailings from floodplain of the Animas at Eureka and Howardsville to the Mayflower tailings site in 1997. Monthly water quality data in segment 3a were collected by the USGS, and others, at Howardsville downstream from Cunningham Creek (A53), below Arrastra Gulch (A60), and in Silverton above Cement Creek (A68).

The data at A53 and A60 show that Cd, Cu, Mn, and Zn concentrations are lower than in segment 2 owing to dilution from streams with low metal content. A53 was sampled on 15 different dates and A60 on 8 different dates during 1998-1999. The dissolved Zn at these two locations is among the lowest in the basin. The higher Al at A60 shown in Table 8.2b reflects the concentration during the winter low flow. No winter data was obtained at either A53 or A60 before 1998. A large increase in the concentration of Cd, Cu, Mn, and Zn occurs in segment 3a between Arrastra Gulch and Silverton (A68).

Stream pH in segment 3a is consistently above 6.0 and is the highest of the contested segments (3a, 4a, and 9b). This pH contributes to the low concentrations of dissolved Al, Cu, Pb, and Fe, but is not sufficiently high to affect dissolved Cd, Mn, or Zn concentrations.

Aquatic life: Figure 8.5 compares the concentrations of dissolved Cd, Cu, Mn, and Zn to chronic TVS at A68 using the WQRM. Comparison of the 85th percentile concentrations of Cd, Mn, and Zn, to concentrations calculated by the WQRM shows that the 85th percentile method reflects water quality conditions that exist during the base flow and early runoff periods. The ambient concentration of Cd, Mn, and Zn, compared to chronic TVS using flow based hardness shows that these metals exceed TVS for a sustained three to four month period in the winter. Zn exceeds TVS year round, and exceeds the ambient standard previously adopted by the WQCC during most of the winter period.

Table 8.2b(i.) Comparison of ambient quality to TVS and adopted water quality standards in segment 3a. Units are in micrograms per liter except pH (s.u.) and hardness (mg/l).

Site		Hard	pH	Al	Cd	Cu	Fe trec	Fe Dis	Pb	Mn	Zn
	TVS		6.5	87	1.1	10	1000	--	2.9	1700	130
	WQS		6.5	87	1.7	11	194	132	3	1000	540
A53	'97-'99		7.0	83	2.1	4	86	54	Bdl	262	304
A60	'97-'99		6.6	150	2.4	5	--	Bdl	Bdl	214	277
A68	'97-'99	115	6.2	115	3.0	9	227	120	Bdl	2500	900

Bdl=Below detection limits.

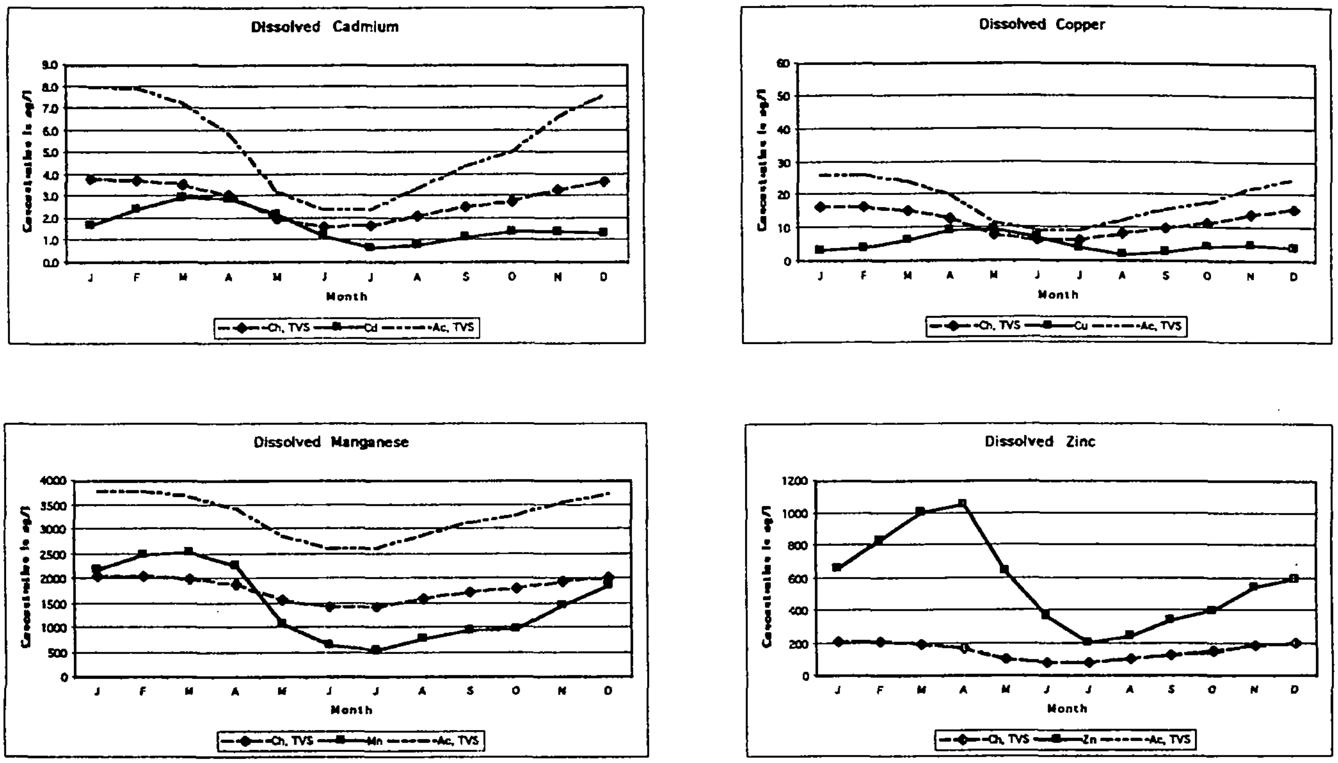


Figure 8.5 Comparison of flow-adjusted target dissolved metals derived from the water quality regression model to chronic table value standards at A68, the Animas River at Silverton. Stream flow is the average monthly flow at A68, 1993 to 1999. Table value standards are computed from the flow-hardness regression. Computed values are for the 15th day of each month.

The 85th percentile method at A68, the most intensively sampled location (n>90) on the segment, shows levels of Al, Cd, Mn, and Zn exceed the adopted WQS. The WQRM, shown in Figure 8.5, indicates there has been no increase in concentrations of Cd, Cu, and Zn between the pre- and post-1997 period, however it does suggest a higher concentration of Mn since 1997. The WQRM was not used for dissolved Al, Fe, or Pb because too many values were less than detection.

Dissolved As, Th and Se were sampled but never detected in the segment. Dissolved Ag, Cr, Hg, Ni, were detected in less than 5% of the samples, but none exceeded aquatic life criteria.

Human health: Samples from the main stem analyzed for total recoverable Sb, As, Ba, Hg, Ni, Cr, and Ag never exceeded water supply MDL criteria. Samples analyzed for total recoverable Be, Cd, and Pb, exceeded water supply MDL criteria in less than 11% of the samples

Agriculture: Mn is the only constituent to exceed the 200 ug/l agricultural criterion more than 15% of the time at the three stations evaluated. Since there is no irrigation, this criterion is not relevant.

Arrastra Gulch

Arrastra Gulch, a tributary to segment 3a, was previously inadvertently not included in any of the segments in the upper basin. Mines in the Little Giant, Woodchuck and Silver Lake sub-basins have since been extensively investigated by DMG (Herron and others, 2000). The area around Silver Lake at the headwaters of Arrastra Gulch was mined as late as the 1950's. Many remnants of the mining days are still present. Access to most of the mines in the basin is by foot or helicopter (Herron and others, 2000). The relatively small metal loads and difficult access results in the remediation potential of these sites as being minimal and very expensive. Trout electroshocking in 1976 and 1998 indicate trout do not live in Arrastra Gulch (Fishery Report, Chapter VI-Appendix 6A). Of the five samples taken in Arrastra Gulch, Cd, Cu, and Zn concentrations exceed TVS. Of the one sample taken during June, at maximum high flow, the hardness was very low resulting in the Cu value double that of the TVS acute toxicity value.

Table 8.2b(ii.) Comparison of ambient quality to TVS in Arrastra Gulch. Units are in micrograms per liter except pH (s.u.) and hardness (mg/l).

Site		Hard	pH	Al	Cd	Cu	Fe Trec	Fe dis	Pb	Mn	Zn
	TVS	70	6.5	87	0.79	6.6	1000	--	1.7	1500	87
Arrastra		70	7.4	Bdl	1.4	8	14	13	Bdl	Bdl	200

Bdl=Below detection limits.

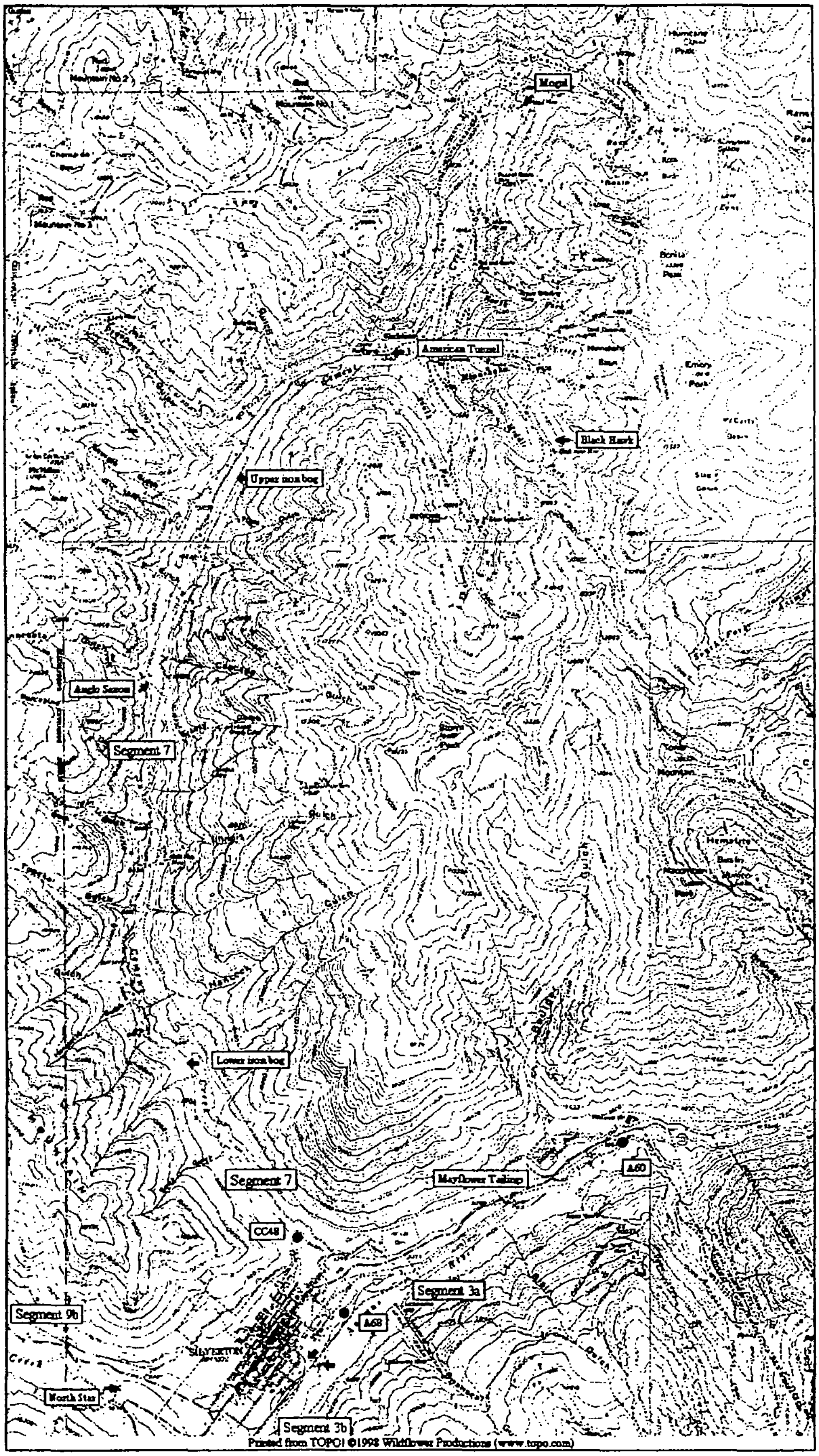


Figure 8.6 Boundaries of Segment 7 of the upper Animas Basin and selected monitoring locations

Segment 3b

This segment is a short reach of the Animas River between Cement Creek and Mineral Creek, Figure 8.4. It follows the east edge of Silverton. The Silverton municipal discharge is to this segment. There are no water quality stations on segment 3b. Cement Creek adds low pH (3.8 to 4.5) and metal rich water which mixes with high pH (6.0 to 7.3) water in the Animas River. Mixing of the two streams with differing pH causes rapid formation of Al and Fe colloids, which begin to settle in the reach (Schemel and others, 1999).

Segment 7

Segment 7 is the entire Cement Creek watershed, Figure 8.6. The American Tunnel (AT) at Gladstone, about seven miles upstream from Silverton, is an important dividing point in the watershed. South Cement Creek and Prospect Gulch enter Cement Creek a short distance below the AT. Mines with metal rich adit drainage and waste rock are found in South Cement Creek, Prospect Gulch, and other drainages downstream from the AT. Data was collected from over 40 waste rock piles and 29 mine openings that had active drainage within the Cement Creek basin.

SGC has treated the discharge from the AT since the 1960's, and levels of treatment have periodically increased over the years. By 1989, the treated discharge from the AT was an insignificant source of metals to Cement Creek. The AT was partially sealed in late1996, and SGC used part of the additional treatment capacity of the plant to remove metals from Cement Creek above the AT. All or most of the flow of Cement Creek above the AT was treated at the AT plant for about eight months each year between September 1996 and May 1999 (Larry Perino, personal communication). The watershed above the AT includes North Cement Creek and Ross Basin. Several mines in these areas are major contributors of Cu and Zn to Cement Creek. Synoptic sampling, (Kimball and others, 2000), in September 1996 showed that the area above the AT accounted for about 18 percent of the dissolved Zn load and nearly 40 percent of the dissolved Cu load at CC48. During the months SGC treated the flow of Cement Creek the Zn concentration at CC48 was reduced by about 212 ug/l or roughly 20 percent. Cu was reduced by an average of 15 ug/l or 27% to 54% for the same period.

Eighty percent of the Zn and over 60% of the Cu enter Cement Creek downstream from the AT. South Cement Creek is an important source of Fe and Zn. Large quantities of Al and Fe enter Cement Creek between Prospect Gulch and Silverton. USGS tracer studies (Kimball, 2000) identified Ohio, Minnesota, and Prospect Gulches as important metal sources.

Table 8.2c. Comparison of ambient quality, 1997-99 with ambient quality, 1991-94 in segment 7. Units are in micrograms per liter except pH (s.u.) and hardness (mg/l).

Site		Hard	pH	Al	Cd	Cu	Fe Trec	Fe dis	Pb	Mn	Zn
	TVS						Not applicable				
	'91-'94		4.4	4300	5.4	110		5480	20	1500	930
CC48	'97-'99		3.8	3164	2.3	84	2585	4823	13	1824	817

These watersheds drain the acid-sulfate system, which dominates the western half of the Cement Creek basin (see Chapter VII), and are major sources of Al, Cu, Fe, and Zn.

Data from Cement Creek at Silverton, CC 48, shows reduced levels of Cd and Mn since treatment of Cement Creek above the AT began in October 1996. Except for Mn, this is reflected in 85th percentile data shown in Table 8.2c. Although the data in Table 8.2c suggests an increase in the average Mn level, the WQRM, after accounting for variation caused by stream flow and seasonality, shows that it has been reduced. No change in the levels of dissolved Al or Fe at Silverton was measurable by the WQRM after treatment of upper Cement Creek was started. Treatment of Cement Creek will end after SGC completes their obligation under the Consent Decree.

The WQRM, Figure 8.7, shows that the highest concentrations of dissolved Al, Fe, Mn, and Zn occur during the base flow period. The regression equations are based on data collected after the SGC consent decree was implemented, therefore these metals enter Cement Creek downstream from the AT. In contrast to Al, Fe, Mn, and Zn dissolved Cu concentration peaks during runoff, Figure 8.7. This result suggests a different mechanism is responsible for Cu loading in Cement Creek.

The pH of Cement Creek is less than 5.0 for all seasons and stream flows. This low pH assures that most metals remain in the dissolved state.

Aquatic life: Levels of Al, Cd, Cu, Pb, and Zn are acutely toxic to aquatic life throughout Cement Creek. Toxic thresholds are exceeded most of the year for all of these constituents. Dissolved Ag exceeded chronic aquatic life criteria in 8% of the samples at CC48.

Human health: The concentration of total recoverable Th and F exceed human health criteria in more than 15% of the samples. Concentrations of total recoverable Be, Cd, Pb, and Ni exceed human health criteria in 5% to 8% of the samples at CC48. Drainage near the Lark, Joe and John, Kansas City, and Henrietta mines in Prospect basin and the Mogul and Red and Bonita mines in the Ross basin have concentrations of total recoverable Sb, As, Be, Cu, Hg, and Zn that exceed water supply MDL criteria.

Agriculture: Mn is the only constituent to significantly exceed agricultural criteria at CC48 but since there is no irrigated lands this criteria does not apply. Drainage near the mines noted in the previous paragraph have concentrations of As, Cd, Cu, Pb, and Zn that do not meet agricultural criteria.

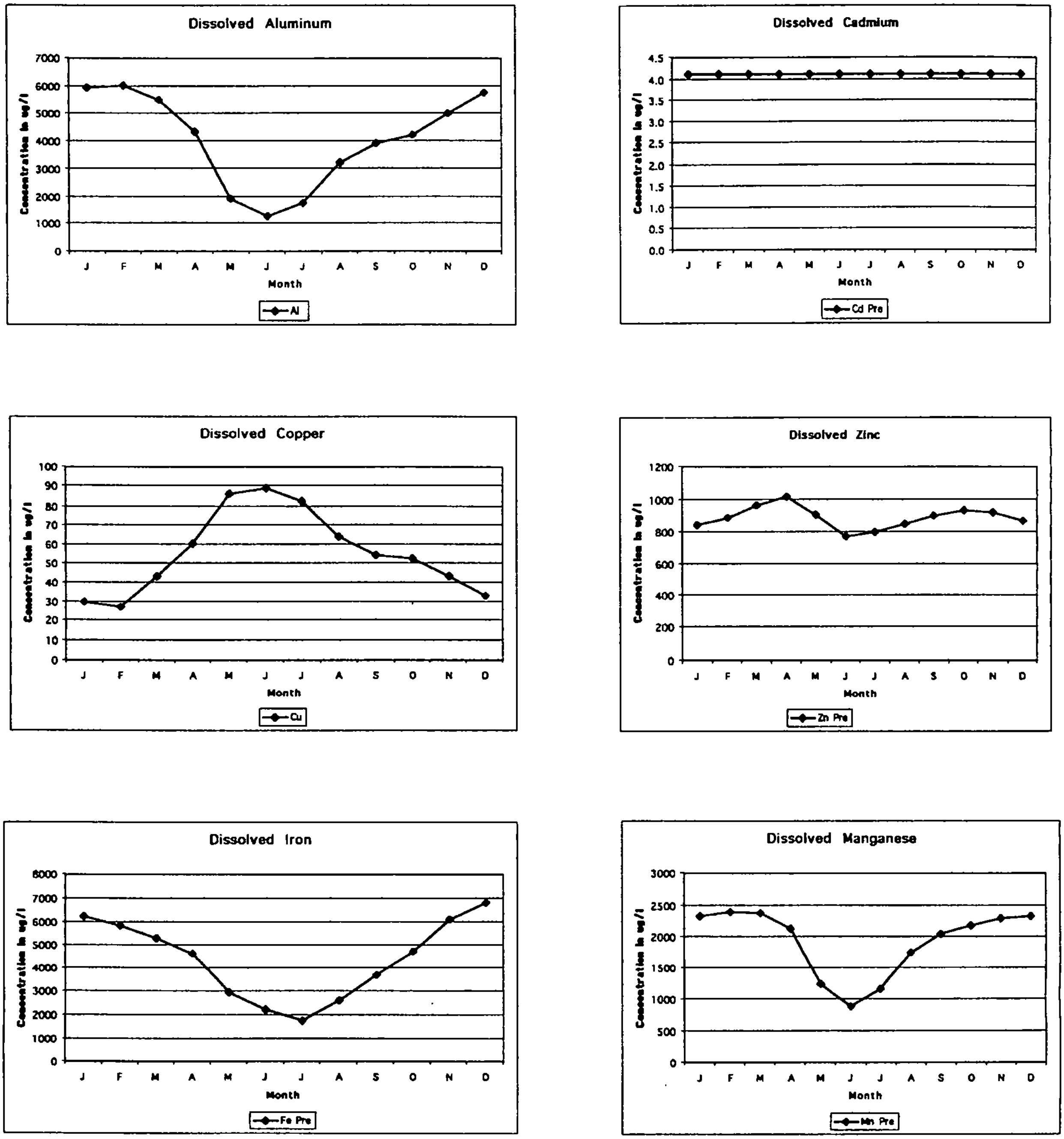


Figure 8.7 Comparison of flow-adjusted target dissolved metals derived from the water quality regression model at CC48, Cement Creek at Silverton. Stream flow is the average monthly flow at CC48, 1993 to 1999. Computed values are for the 15th day of each month. Concentrations are for the period after the SGC Consent Decree was implemented.

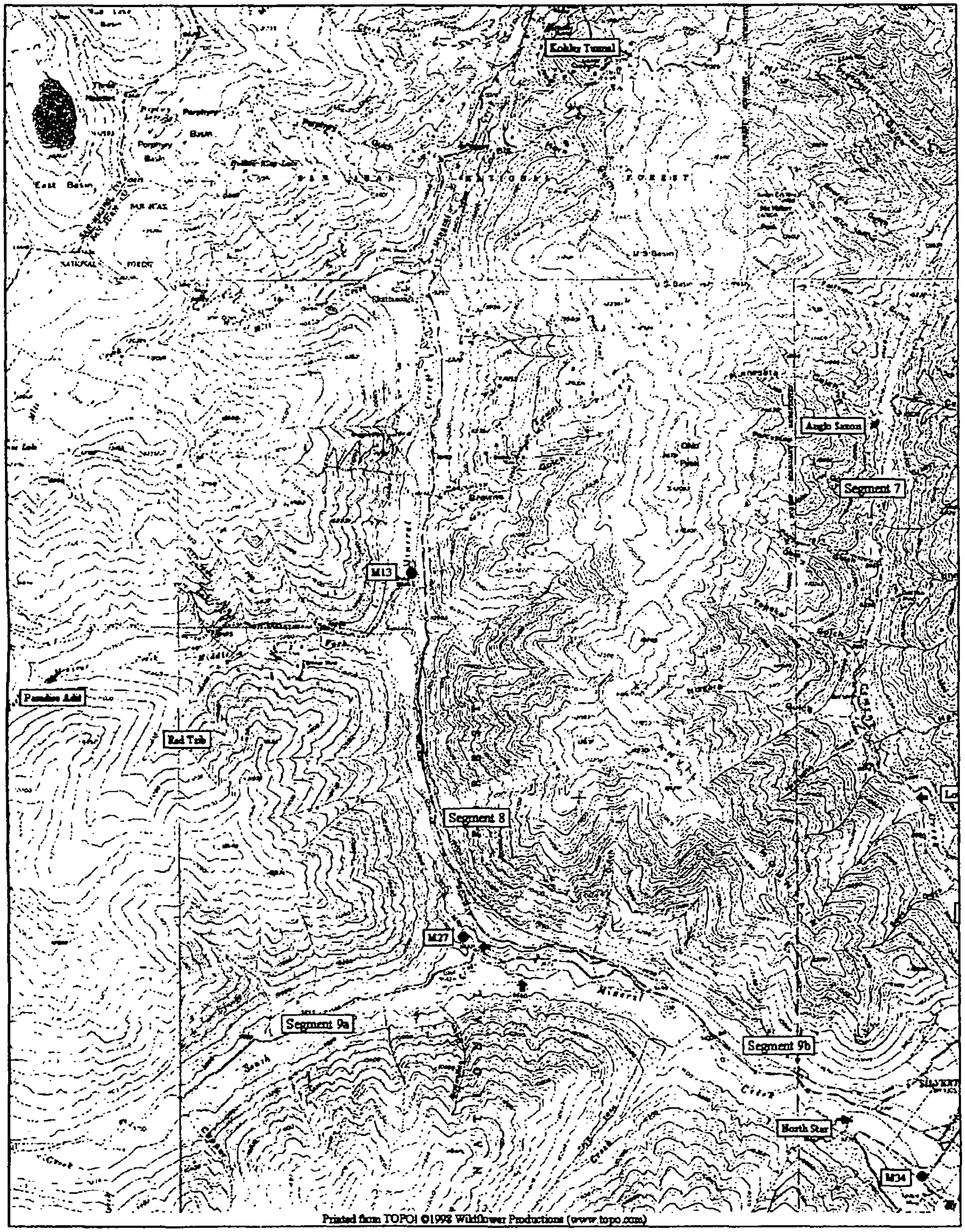


Figure 8.8 Boundaries of Segments 8 and 9b of the upper Animas Basin and selected monitoring locations

Segment 8

Segment 8 is the main stem of Mineral Creek, which begins on Red Mountain Pass and extends to the confluence of South Mineral Creek, Figure 8.8. Most of the data in this segment were collected above the confluence of the Middle Fork with Mineral Creek (M13) and above the confluence with South Mineral Creek (M27). This segment has the fewest number of mines, but some of the highest concentrations of dissolved Al, Cu, Fe, and Zn in the Upper Animas Basin, Table 8.2d. Thirty mine openings with active drainage and 20 waste rock piles were sampled throughout Segment 8. Detection of Cr, Se, Th, Hg, and Ni were rare and only one value (for Ni) exceeded a water quality criterion.

Most of the metals shown at site M13, just above Middle Fork, are from the Red Mountain Pass area, which drains the acid-sulfate geologic system discussed in Chapters IV and VII. The Kohler-Longfellow mine complex is located in this area, and is the largest single source of Zn anywhere in the basin. The site also produces large quantities of Cd and Cu. Partial remediation at the Kohler-Longfellow and Carbon Lakes sites near Red Mountain Pass in 1997 has contributed to reduced the levels of Al, Cd, Cu, Fe, Pb, and Zn in Mineral Creek above South Mineral Creek (M27).

Table 8.2d. Comparison of ambient quality, 1997-99 with ambient quality, 1991-94 in segment 8. Units are in micrograms per liter except pH (s.u.) and hardness (mg/l).

Site		Hard	PH	Al	Cd	Cu	Fe Trec	Fe Dis	Pb	Mn	Zn
	TVS					Not applicable					
	'91-'94	196	4.5	5200	3.2	190	2400	6900	23	860	920
M13	'98-'99		6.3	67	4.9	79	--	128	*	452	1207
M27	'97-'99	206	4.3	5500	1.8	112	4819	4417	*	783	723

* The detection limit for Pb at these sites was 30 ug/l, which is too high to be used.

The Middle Fork of Mineral Creek, entering Mineral Creek downstream from M13, is the primary source of acid water, Al, and Fe in the Mineral Creek basin, Table 8.2d. The acid water, Al, and Fe are from water draining deposits of quartz-sericite-pyrite (QSP). Kimball's (personal communication) tracer study of Mineral Creek found that colloidal Cu from the Red Mountain Pass area was re-dissolved in Mineral Creek after mixing with acid water from the Middle Fork. Lower concentrations of Zn measured at M27 are due to dilution from tributary waters including the Middle Fork.

Aquatic life: The water quality of the segment, as shown in Table 8.2d, is not suitable for aquatic life owing to low pH, and high concentrations of dissolved Al, Cd, Cu, Fe, Pb and Zn. Concentrations of Al, Cu, and Zn are acutely toxic to aquatic life in segment 8. One of three dissolved Ag samples at M13 and M27 exceeded criteria for aquatic life.

Human health: Total As, Cd, and Pb exceed water supply MDL criteria in the main stem at M13 above the Middle Fork. Drainage from the Kohler-Longfellow complex has concentrations of Cu and Zn that exceed water supply MDL criteria. Fluoride was detected in over half of the samples, but no value exceeded the water supply MDL criterion.

Agriculture: Water quality in several areas of the segment is not suitable for agriculture. All of the contaminents originate from the Kohler-Longfellow complex near Red Mountain Pass. Concentrations of As, Cu, and Mn exceed agricultural criteria at M13. Cu and Mn agricultural criteria apply to irrigation, which is not a use of the segment. Cd and Zn exceed agricultural criteria near Red Mountain Pass.

Segment 9b

This segment is the main stem of Mineral Creek from South Mineral Creek, segment 9a, to the confluence with the Animas River, Figure 8.8. The WQCC adopted the aquatic life use and numeric standards for Al, Cd, Cu, Fe, Pb, Mn, and Zn based on remediation potential of metal loading from the Red Mountain Pass area. EPA disapproved ambient standards for Cu and Fe because they were not consistent with requirements in the federal water quality standards regulations (40 CFR 131.11). The North Star mine is the only mine site on the segment above the sampling station at M34. The majority of the metals in the segment are from upstream in Segment 8. As, Sb, Be, Cr, Ni, Se, Hg, Ag, and Th were rarely or never detected at M34, above Silverton, and never exceed aquatic life, human health or agricultural criterion

Aquatic life: The 85th percentile method shows that Al exceeds both chronic and acute criteria (750 ug/l) for aquatic life at M34. The level of Al is about three times higher than the acute criterion for aquatic life for more than four months in the winter. Cu and Zn exceed acute and chronic TVS, but they are equal to or less than the temporary modifications adopted by the WQCC in 1995. Cu and Zn exceed TVS most of the year, Figure 8.9. The benefits of partial remediation at Kohler-Longfellow and Carbon Lakes are measurable in Mineral Creek, at M34. Cu and Zn levels are lower than the adopted temporary modifications. After accounting for the effects of stream flow and season, the WQRM shows an average reduction in Cu and Zn of 11 and 98 ug/l, respectively, at M34 since 1995. Cd exceeds TVS during the spring runoff. Pb exceeded the aquatic life criterion in 2% of the samples.

Table 8.2e. Comparison of ambient quality to TVS and adopted water quality standards in segment 9b. Units are in micrograms per liter except pH (s.u.) and hardness (mg/l).

Site		Hard	pH	Al	Cd	Cu	Fe Trec	Fe Dis	Pb	Mn	Zn
	TVS		6.5	87	1.9	18	1000	300	6.1	2200	237
	WQS		6.5	87	1.7	57	5515	3415	7	1000	544
M34	'97-'99	228	4.8	2097	1.6	49	4233	3300	2	471	482

Data collected since 1995 shows the importance of Al as a contaminant in this section of Mineral Creek. Most of the dissolved Al is from the Middle Fork of Mineral Creek. The pH of Mineral Creek at M34 is less than 5.5 more than 50% of the time during base flow. Colloidal Al forms when the pH rises above 5.5 (Nordstrom and others, 1999). Most of the Al, therefore, remains dissolved in the winter, forming colloids after Mineral Creek mixes with the Animas River. In the summer, most of the aluminum is in the colloidal form. High Fe concentrations accompany the high Al values observed at M34. The Fe is from the same quartz-sericite-pyrite assemblage as the Al.

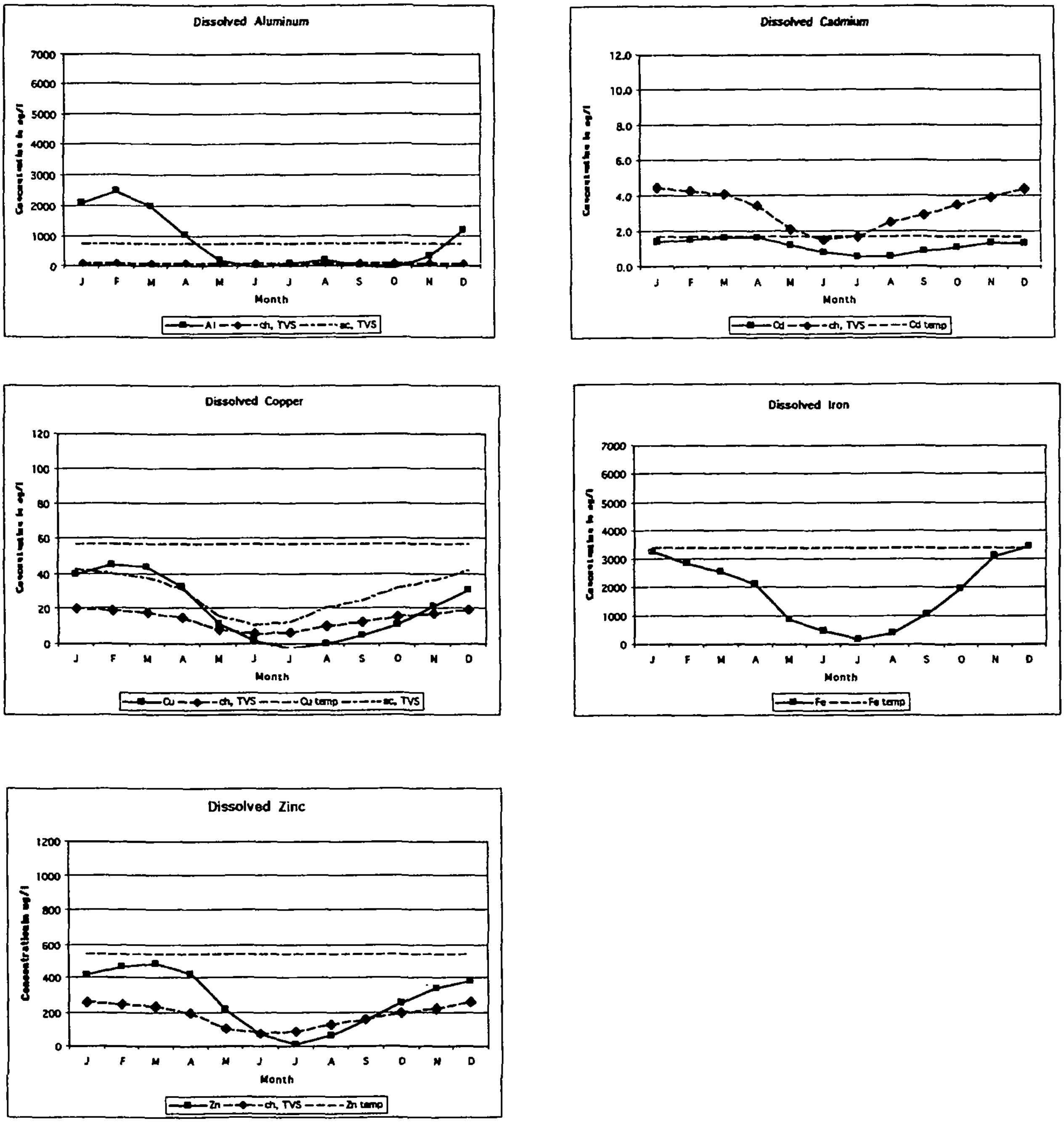


Figure 8.9 Comparison of flow-adjusted target dissolved metals derived from the water quality regression model to chronic table value standards at M34,Mineral Creek near Silverton. Stream flow is the average monthly flow at M34, 1993 to 1999. Table value standards are computed from the flow-hardness regression. Values are for the 15th day of each month.

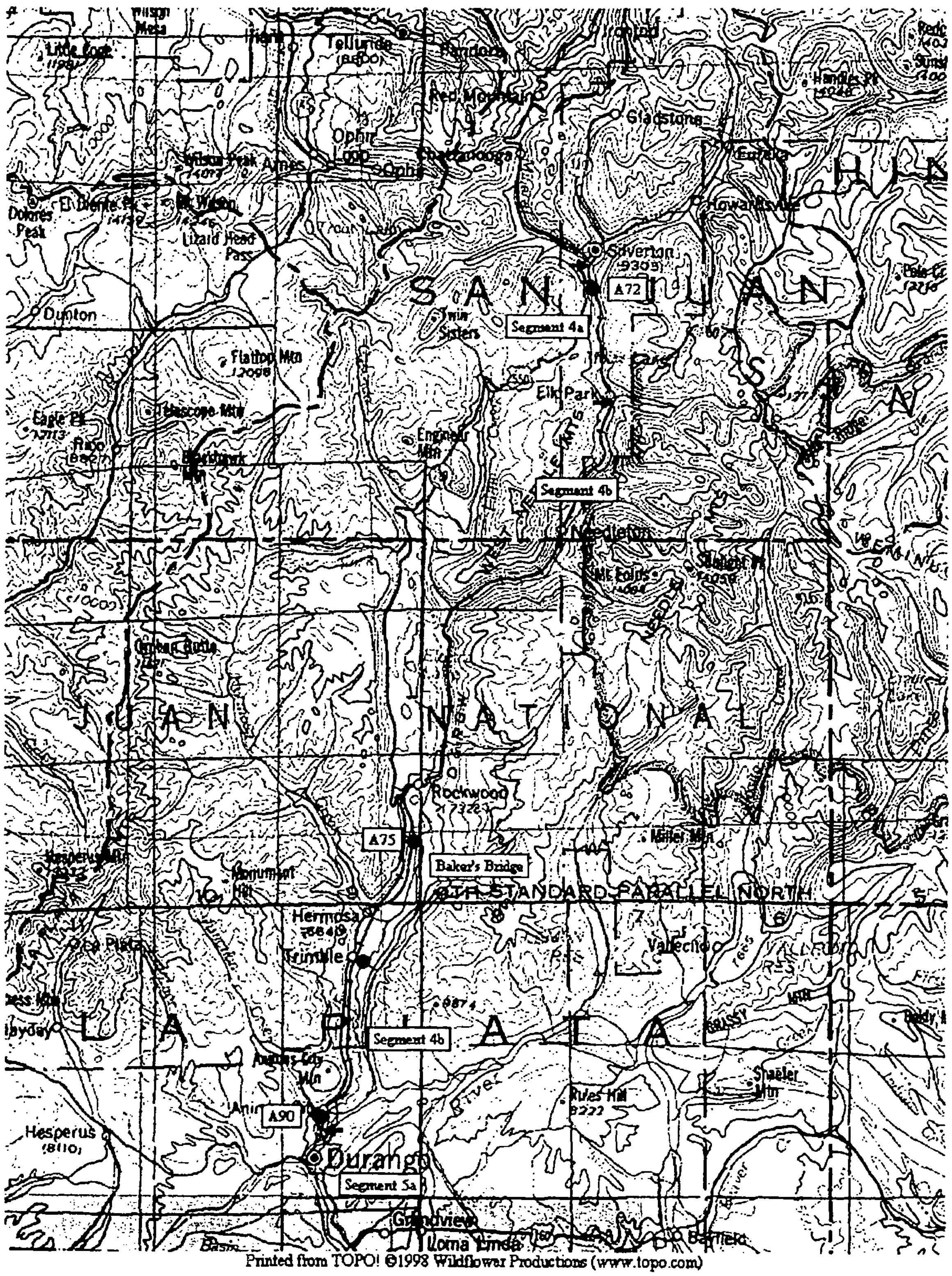


Figure 8.10 Boundaries and selected monitoring locatins of Segments 4a, 4b, and 5a of the upper Animas Basin

Human health: One percent of the total recoverable Pb samples exceeded water supply MDL criteria. Barium and fluoride were detected in most of the samples, but never exceeded water supply MDL criteria.

Agriculture: Mn is the only constituent that does not meet agricultural criteria. The Mn criterion is a crop irrigation requirement, which is not a use of water in the segment.

Segment 4a

Segment 4a extends from the confluence of Mineral Creek and the Animas River to Elk Creek about 5.5 miles downstream, Figure 8.10. Water quality investigations of the early 1990's found minimal aquatic life in this segment. Dissolved Zn, followed by dissolved Cd and Cu, were thought to be the main cause of impairment. The effects of Al and Fe were also thought to contribute to the impairment. Improvement of this reach so that it is capable of supporting aquatic life is one of the goals of the ARSG. Sb, As, Be, Cr, Ni, Se, and Th were rarely detected and never exceeded an aquatic life, human health, or agricultural criterion.

Aquatic life: Data for segment 4a, the Animas River below Silverton, as measured at A72, indicate levels of Al, Cd, Cu, Fe, Mn, and Zn all exceed water quality standards for aquatic life using the 85th percentile method, Table 8.2f. The highest levels of Al, Cu, Fe, Mn, and Zn are observed during base flow. The pH is commonly less than 6.0 during the base flow. Comparison of pre-1997 data with post-1997 data, using the WQRM, shows no change in water quality over the 1991 to 1999 period. Limited base flow data was available at A72 prior to 1995 because the site lies in the path of a major snow slide chute and winter sampling was inadvisable for safety reasons. Most base flow data obtained since 1995 was obtained by residents familiar with local weather and avalanche danger.

The WQRM shows Cd and Cu slightly exceed chronic TVS during portions of the year, Figure 8.11. Al exceeds the chronic criterion for aquatic life for most of the base flow period, Figure 8.11. Zinc exceeds both acute and chronic TVS year round and exceeds the temporary modification adopted by the WQCC during base flow.

The data indicate segment 4a functions chemically similar to segment 3b. Complex mixing reactions involving the formation of Al and Fe colloids and co-precipitation of Cu, and Zn that originate in Cement and Mineral Creeks are active during parts of the year.

Table 8.2f. Comparison of ambient quality to chronic TVS and adopted water quality standards in segment 4a. Units are micrograms per liter except pH and hardness (mg/l).

Site		Hard	pH	Al	Cd	Cu	Fe Trec	Fe Dis	Pb	Mn	Zn
	TVS		6.5	87	1.6	15	1000	300	4.7	2000	194
	WQS		6.5	87	1.6	13	2000	390	5	1000	520
A72	'97-'99	180	5.8	554	2.0	20	2064	2326	Bdl	1600	723

Human health: Total recoverable Cd exceeded water supply MDL criterion in 4% of the samples. Total recoverable Pb exceeded water supply MDL criterion in 2% of the samples.

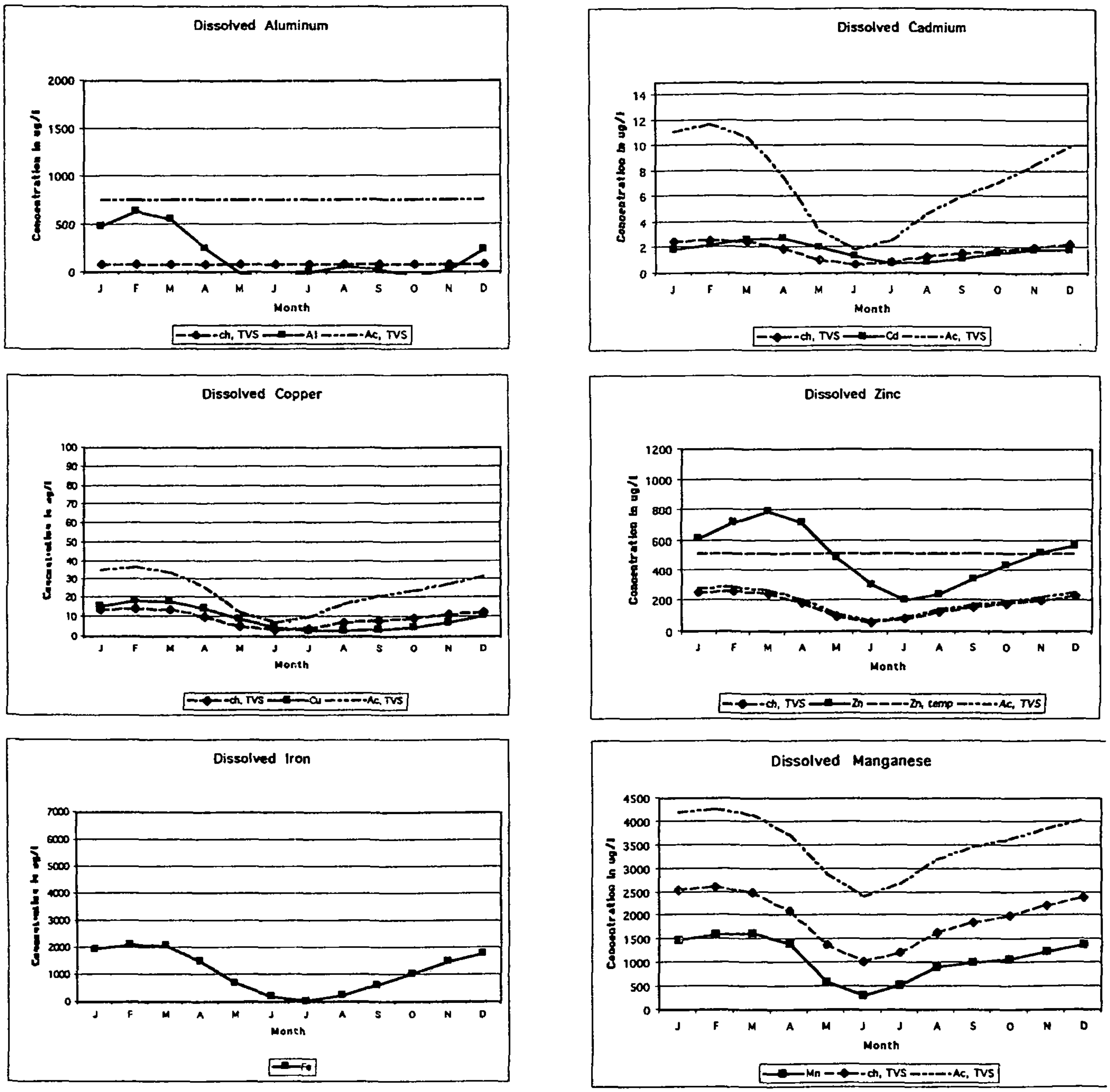


Figure 8.11 Comparison of flow-adjusted target dissolved metals derived from the water quality regression model to chronic table value standards at A72, the Animas River below Silverton. Stream flow is the average monthly flow at A72, 1993 to 1999. Table value standards are computed from the flow-hardness regression. Computed values are for the 15th day of each month.

Agriculture: Cd exceeded agricultural criterion in 2% of the samples. Mn exceedances of agricultural standards are not relevant since there is no irrigation.

Segment 4b

This segment extends from Elk Creek in the Animas River canyon to Junction Creek near downtown Durango, Figure 8.10. Investigations by the ARSG (Cady and others, 1996) and the USFS did not identify additional sources of metals within the canyon reach. Concentrations of dissolved Al, Cu, Fe, and Zn are attenuated as metal free water enters the segment and as the pH rises. The Animas River exits the canyon about 27 miles below Elk Creek near Baker's Bridge.

Sand and gravel mining, agriculture, and urbanization in the Animas Valley replaces hardrock mining as the human-related factors that impact water quality after the river leaves the canyon. Water quality in segment 4b was monitored by the Colorado River Watch program at Baker's Bridge (A75), Trimble Lane (A89), and Durango High School (A90).

Table 8.2g. Comparison of ambient quality to TVS and adopted water quality standards in segment 4b. Units are in micrograms per liter except pH and hardness (mg/l).

Site		Hard	pH	Al	Cd	Cu	Fe Trec	Fe Dis	Pb	Mn	Zn
	TVS		6.5	--	1.2	11	1000	300	3.3	50	147
	WQS		6.5	--	1.6	17	1509	300	7	210	182
A75	'97-'98	130	7.5	--	0.5	4	625	--	Bdl	326	159
A89	'97-'98	150	7.1	--	0.3	5	403	--	--	173	120
A90	'97-'98	196	7.6	--	0.2	4	345	--	--	143	112

Bdl=Below detection limit.

Aquatic life: Dissolved Cd, Cu, Pb, and Zn, in segment 4b as measured in the Animas River at the upper most station, Baker's Bridge (A75), between 1997 and 1999 are lower than the adopted standards, Table 8.2g. This improvement may be a reflection of remediation activities undertaken since October 1996 or variances in stream flow conditions that existed when the river was sampled. No discharge measurements are made at Baker's Bridge, therefore stream flow was estimated using concurrent upstream and downstream daily discharges. The WQRM was used to estimate chronic TVS as a function of hardness and Zn concentration. The WQRM did not detect a change in concentration due to upstream remediation. Moreover, Figure 8.12 indicates that dissolved Zn exceeds TVS most of the year.

Water supply: The segment is classified for water supply. Water supply MDL criteria are met for all sampled constituents. The ambient concentration of Mn at Baker's Bridge, A75, shown in table 8.2g exceeds 200 ug/l, however ambient Mn concentrations can be used as the recommended standard.

Agriculture: The ambient concentration of Mn at Baker's Bridge, A75, shown in table 8.2g exceeds TVS for Mn for agricultural use. However, this criterion is applied only for the irrigation of low pH soils. Soils in this segment are known to be moderately alkaline.

Summary

Water quality monitoring between 1997 and 1999 found concentrations of Al and Zn exceeded the standards adopted by the WQCC in 1995 using the 85th percentile methodology in segments 3a, 4a, and 9b. The 85th percentile method shows that higher levels of dissolved Al and Zn occur during the winter low flow, Table 8.3.

Multiple regression analysis of the data collected at four gaging stations between 1991 and 1999 also shows that most of the exceedances are during winter base flow. Stream flow and seasonal factors were not specifically considered when the 1994 standards and goals were set.

Higher concentrations of Al, Cd, Cu, and Zn per unit of discharge occur during base flow than at other times of the year. Zinc concentration elevates during winter base flow, reaching a maximum from around April 15 to the end of May when the peak runoff period begins. Al concentration exceeds chronic criteria for aquatic life in segments 3a, 4a, and 9b from December through May and exceeds acute standards in segments 4a and 9b for the same period. Cu concentration exceeds chronic TVS in segments 4a and 9b during the runoff period. Zn exceeds acute and chronic criteria in all three segments most of the year. Flow and seasonal factors that affect the concentration of priority metals will dictate remediation strategies and the ability to meet water quality goals for aquatic life.

Remediation activities undertaken by SGC, ARSG, and others show measurable reductions in Cd, Cu, and Zn in Cement Creek at Silverton during parts of the year. Reductions in Cd, Cu, and Zn have also been observed in Mineral Creek.

Table 8.3 85th percentile dissolved concentrations by season for 3a, 4a, and 9b. Units are in micrograms per liter except pH (s.u.)

		pH	Al	Cd	Cu	Fe	Pb	Mn	Zn
3a	Apr-Oct	6.4	70	1	5	120	Bdl	1100	420
	Nov-Mar	6.1	133	4.5	10	120	Bdl	3400	1179
4a	Apr-Oct	6.1	80	.0	8.3	895	Bdl	1070	430
	Nov-Mar	5.5	752	2.3	21	2749	1.0	1960	752
9b	Apr-Oct	6.1	88	0.4	7	1760	Bdl	310	239
	Nov-Mar	4.8	2568	1.8	54	3700	1.4	542	530

Bdl=Below detection limit.

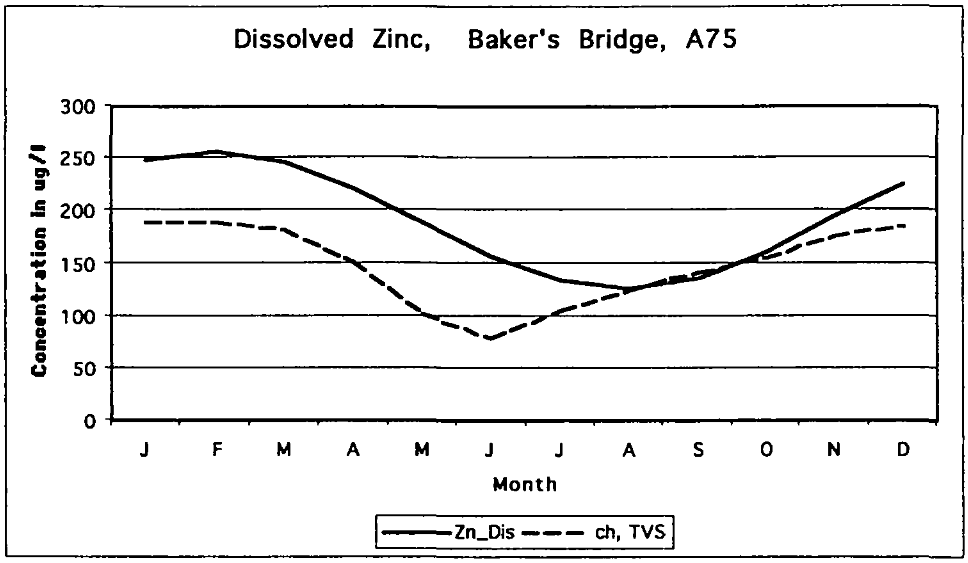


Figure 8.12 Comparison of flow-adjusted dissolved Zn derived from the water quality regression model to chronic table value standards at A75, the Animas River at Baker's Bridege. Stream flow is the average monthly flow at A75, 1993 to 1999. Table value standards are computed from the flow-hardness regression. Computed values are for the 15th day of each month.

ASSESSMENT OF SOURCES

The concentration of solutes in the waters of the Upper Animas Basin reflects natural and human-related factors. The acid environment that exists today results from geologic processes that formed the San Juan caldera and the subsequent circulation of fluids rich in sulfur and base metals, as described in Chapter VII. Oxidation of pyrite, the most widespread sulfide mineral in the basin, is the source of most of the acid water. Mining exposed additional sulfur bearing minerals to oxygen in adits, stopes, and shafts leading to acid mine drainage. Weathered waste rock and mill tailings, rich in metal sulfides, removed from the mines are another source of acid and metals in the water. Minerals containing Al, Cd, Cu, Pb, Mn, and Zn that contact acid waters dissolve, and the metals are transported to the streams. The purpose of this chapter is to identify principal sources of acid water and metals that are "irreversible" or naturally occurring and those that have been aggravated by human activities, and have the potential for remediation, identified as "reversible". This section considers the sources of solutes measured at the gages on Cement Creek, Mineral Creek, and the Animas River.

Runoff Process

To better understand sources of metals, it is helpful to understand runoff processes. The runoff model used in this discussion is taken from Knighton (1984).

Water reaching the ground surface from either rain or snow can follow several paths on its way downslope. Where the maximum rate of absorption exceeds the rate of receipt, water infiltrates the surface and either moves downward to replenish the groundwater reservoir or flows laterally as throughflow. Throughflow may be diffuse when water flows through the matrix of the soil or mine waste or concentrated in faults or fractures of variable size or location. Water moves more slowly within the soil so runoff following this path reaches the stream some time after the precipitation event(s). Moreover, throughflow has the opportunity to contact acid bearing material or soluble salts for a sustained period, thereby increasing the quantity dissolved. Mine workings expand the size and frequency of the faults and fractures. Alteration of natural flow paths creates "pipes" for throughflow and groundwater.

Runoff is also generated as overland flow. This is most common in the Animas Basin during the annual snowmelt period. Overland flow occurs when the ground becomes saturated or when rainfall intensity exceeds the infiltration capacity of the soil mantle. Saturation overland flow depends on the moisture content of the soil and waste material before, during and after snowmelt or other precipitation events. If the precipitation is sufficient to saturate the deeper and less permeable soil layers, throughflow will be deflected closer to the soil surface as the level of saturation rises. If the soil becomes saturated to the surface, saturation overland flow occurs.

Overland runoff also occurs if rainfall intensity exceeds the infiltration capacity of the soil mantle. This type of runoff is produced more or less instantaneously and simultaneously over a basin during a heavy rain. These events occasionally produce high flood peaks and high concentrations of suspended sediment and metals, but they are relatively infrequent and produce a small portion of the metal load on an annual basis. These events are of most concern if they cause metals concentration to approach short-term or acutely toxic thresholds. This section is primarily concerned with long-term toxic events thus metals produced from single storm events are only briefly considered.

Water reaching the Animas River at A72 will have followed one of the several routes described above. Each route gives a different response to snowmelt or rainfall in terms of the volume of flow, the timing of contributions to the stream, and the concentration of solutes. Figure 8.13 shows the average annual hydrograph for the Animas River below Silverton, A72. The total flow at A72, for convenience, is divided into two parts: base flow and "seasonal runoff". The distinction is based on the time of arrival in the stream rather than the route followed. Groundwater flowing at depth beneath the surface moves relatively slowly, so its outflow into the stream lags behind snowmelt and rainfall and tends to be very regular. Water emanating from "pipes" such as a wastewater treatment plant or a mine adit is also relatively stable. These two sources comprise the base flow that sustains the rivers at A68, CC48, M34, and A72 from November through February.

Seasonal runoff includes the throughflow and overland flow components of the runoff model. It usually starts slowly in March, reaching a peak in mid-June. Runoff lasts through the rest of the summer and fall, several months after the previous winter's snow is gone. The dashed line in Figure 8.13 is the estimated base flow during the seasonal runoff period.

Table 8.4 shows the sources of runoff at the four gages during February, the lowest flow month, and June, the highest flow month. Groundwater, adits, and two permitted point sources comprise the streamflow during February, as seasonal runoff is nonexistent. The discharge from most adits was sampled as a part of the UAA studies. Similar data are available for permitted point sources. Therefore, subtracting known discharges from adits and point sources from the total discharge at base flow gives an estimate of the contribution from groundwater. Adit discharges and loads may be overestimated because most of the low adit flows were sampled in September or October, and it was assumed that they were flowing at the same rate in February. In addition, metal loads from natural ground water sources that enter mines were not subtracted from the discharge load. It was also assumed that all of the flow emanating from the adits reach the nearest gage as surface flow and did not reenter the groundwater.

During high flow measured sources—adits and point sources--were subtracted from the total flow and the remainder partitioned as seasonal runoff (throughflow) or base flow. Base flow, which by definition is relatively constant, for the peak flow month was conservatively estimated to double the February amount. Seasonal runoff was estimated by subtracting measured sources and base flow from the total discharge.

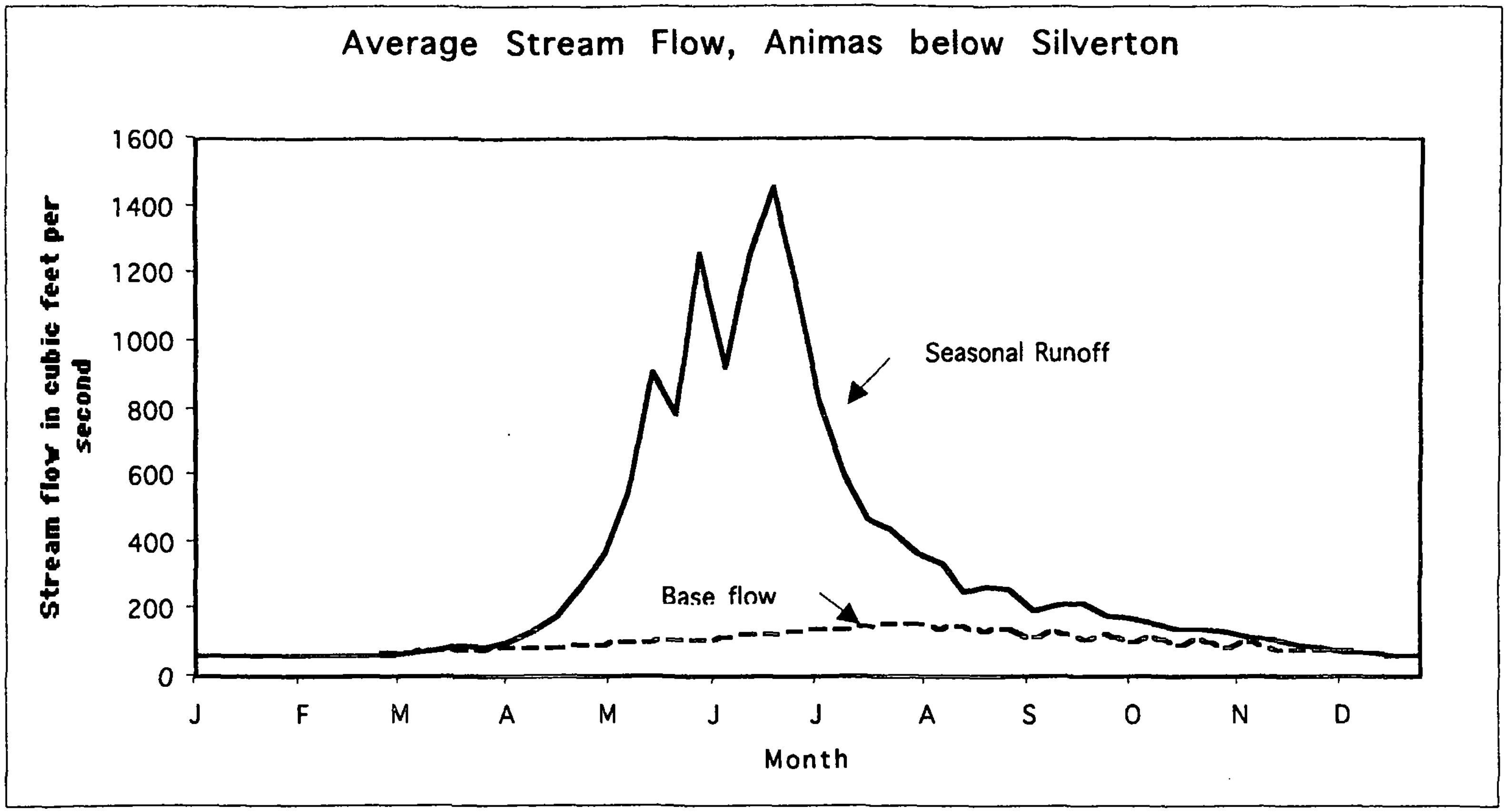


Figure 8.13 Average stream flow, Animas River below Silverton showing the estimated portion that is base flow.

Table 8.4 Sources of runoff in cubic feet per second at the four gages for a base flow and peak flow month

	A68	CC48	M34	A72
Source		February		
Point source	0	2	0	2.2
Adits	8.8	3.3	6.1	18.2
Ground water	19.2	8.7	15.9	39.6
Seasonal RO	0	0	0	0
Total Runoff	28	14	22	60
		June		
Point source	0	2.3	0	2.5
Adits	8.4	7	6	23.4
Ground water	38	18	32	80
Seasonal RO	574	140	458	1161
Total Runoff	620	167	496	1267

Notes: The flows from the three upstream gages and A72 do not add up because there is an ungaged area between the four gages. Throughflow and overland flow both affect the records differently for the two months. The Silverton municipal discharge is between M34 and A72.

Metal Concentrations

This section identifies the sources of metals that make up the instream concentration during different parts of the flow year, that is, base flow and seasonal runoff. The analysis considers the solute load, which is the product of flow times solute concentration (a conversion factor may be included to express the result in pounds, kilograms or other convenient unit). Typically, the solute load is highest when the runoff is high, however, the concentration of metals is more important to the health of aquatic life than the load. Generally, the Animas River and its principal tributaries have the highest concentrations of metals during base flow when the loads are the least. The approach used here, therefore is to remove the effect of stream flow and focus on the percentage of the concentration of target metals from natural and human-induced sources arising during base flow and seasonal runoff.

The WQRM was used to estimate the concentration of total recoverable Al, Cd, Cu, Fe, Mn, and Zn at A68, CC48, and M34. The percentage of the concentration, weighted by the proportion of load, of each metal was allocated to groundwater and adits (base flow), or seasonal runoff. For example, if 20% of the load at a gage came from adits and those sources were removed, the concentration at that gage would drop by 20%. Therefore, 20% of the concentration is attributable to the adits.

During base flow, November through February, all metals were assumed to come from adits or groundwater, therefore the groundwater component was estimated as the total concentration minus the adit component. Seasonal runoff includes metals transported as both overland flow and throughflow from the soil mantle, alluvial fans, and waste rock found in the watersheds. The loads from most adits were measured during both low and high flow periods, therefore the adit contribution was seasonally adjusted. The groundwater component cannot be directly measured during runoff so it was conservatively assumed that it could double between the lowest flow month (February) and the highest flow month (June). In order to double the base flow load for this interval it was necessary to increase the base flow load by 15% per month. Between March and October the concentrations from adits and groundwater were subtracted from the total concentration and the remainder was attributed to seasonal runoff.

Several of the metals change from dissolved species to colloidal or particulate species owing to inflows with different chemistry. In order to minimize the apparent loss of metals due to a change in species, the total recoverable fraction of Al, Cu, Fe, and Zn are used for this analysis. Concentrations of total recoverable Al, Cu, Fe, and Zn should be equal to or higher than dissolved concentrations used for water quality standards and biologic toxicity. The solutes, especially Al and Cu, change from dissolved to colloidal species at pH levels frequently found in the Basin. Figures 8.14 to 8.17 compare total recoverable and dissolved Al, Cu, Fe, and Zn concentrations estimated by the WQRM at the four gaging stations. The secondary vertical axis (right hand) shows the average variation in pH over the annual cycle. One of the most notable features of these four figures is that the concentration of total recoverable and dissolved Al and Cu in the low pH waters of Cement Creek are similar. These graphs also show that there is more Al (Figure 8.14) and Cu (Figure 8.15) in the Animas and Mineral Creek than is indicated by dissolved concentrations used for establishing water quality standards.

Total recoverable Fe concentrations are significantly higher at CC48, M34, and A72 than the dissolved Fe concentration, Figure 8.16. This does not appear to be a function of pH within the pH range observed in the Upper Animas Basin. No graph is shown for Fe at A68 because most of the dissolved values are less than detection.

A second feature is that the concentration of total recoverable and dissolved Zn at all four gage sites is similar despite wide differences in the pH patterns among the four streams, Figure 8.17. The pH of Cement Creek is consistently less than 5.0, while the pH of the Animas at Silverton (A68) fluctuates around 7.0 with very little cyclical variation. Total recoverable and dissolved Zn concentrations at M34 and A72 are nearly the same, even with the strong cyclical pH found in Mineral Creek and moderately strong cyclical pattern at A72.

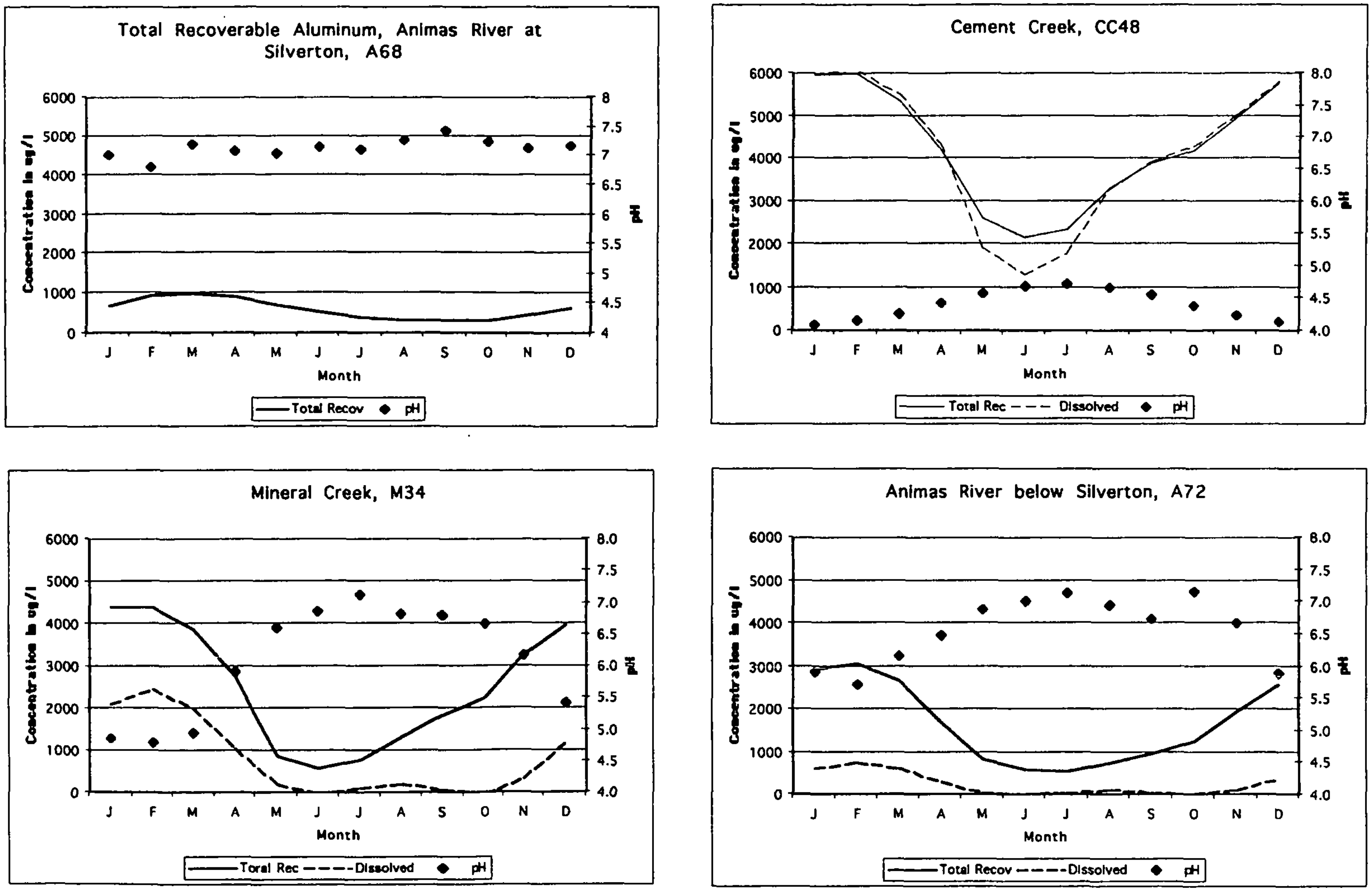


Figure 8.14 Comparison of total recoverable and dissolved aluminum concentrations and the cyclical variation of pH at stream gages in the upper Animas Basin. Dissolved aluminum for the Animas at Silverton, A68, is not shown because most observations are less than detection.

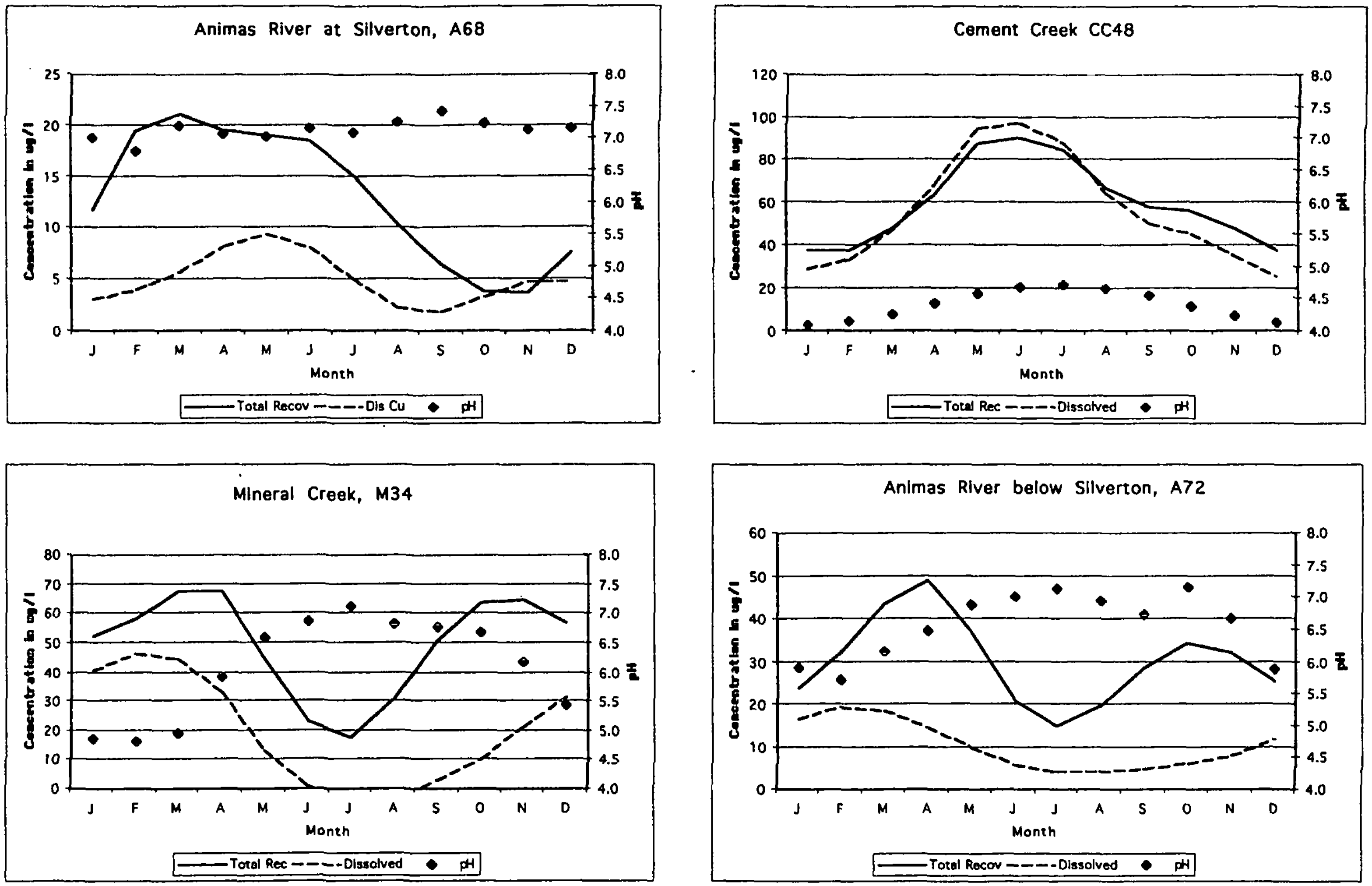


Figure 8.15 Comparison of total recoverable and dissolved copper concentrations and the cyclical variation of pH at stream gages in the upper Animas Basin.

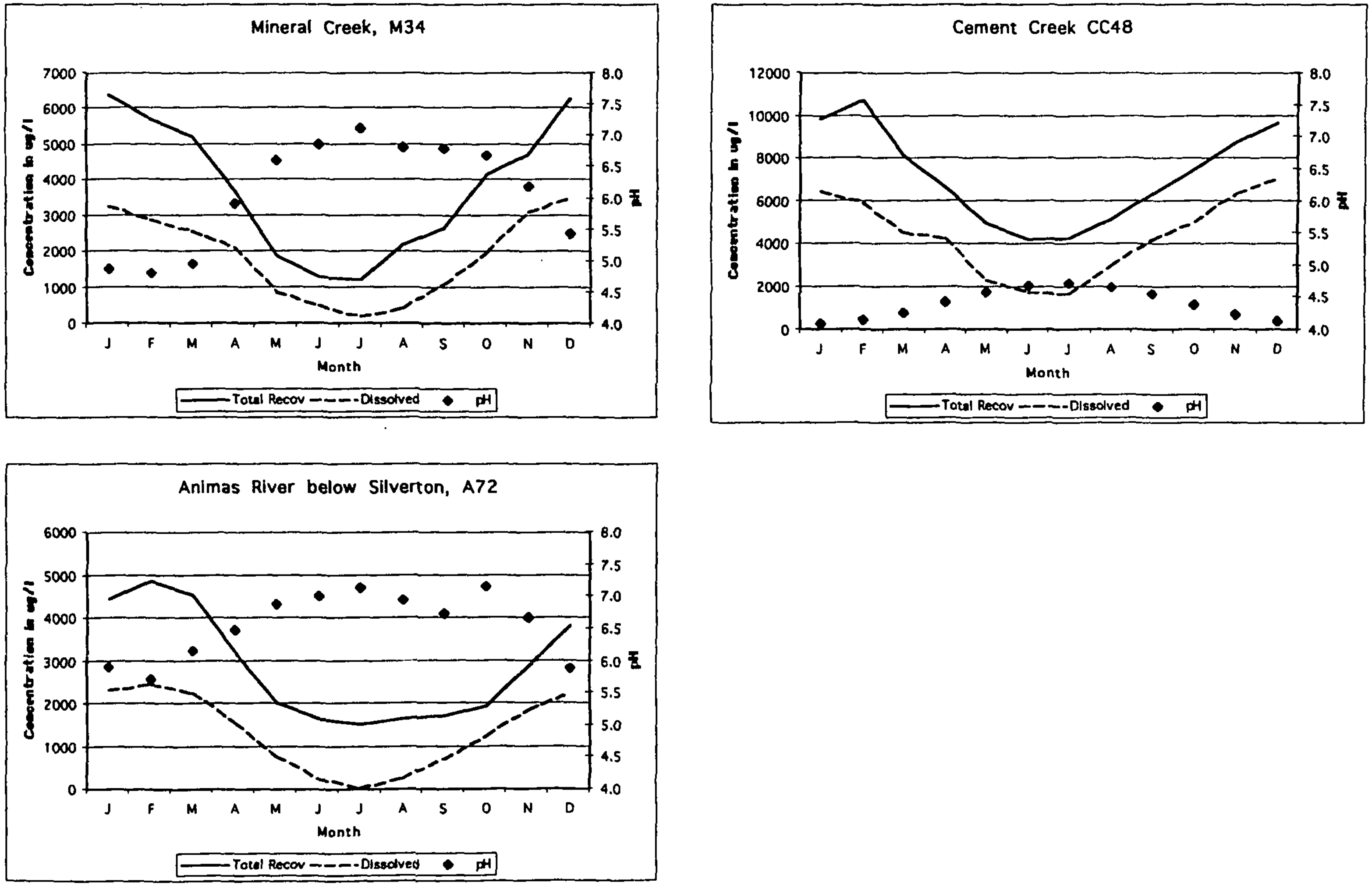


Figure 8.16 Comparison of total recoverable and dissolved iron concentrations and the cyclical variation of pH at stream gages in the upper Animas Basin. Animas at Silverton, A68, is not shown because most observations of dissolved iron are less than detection.

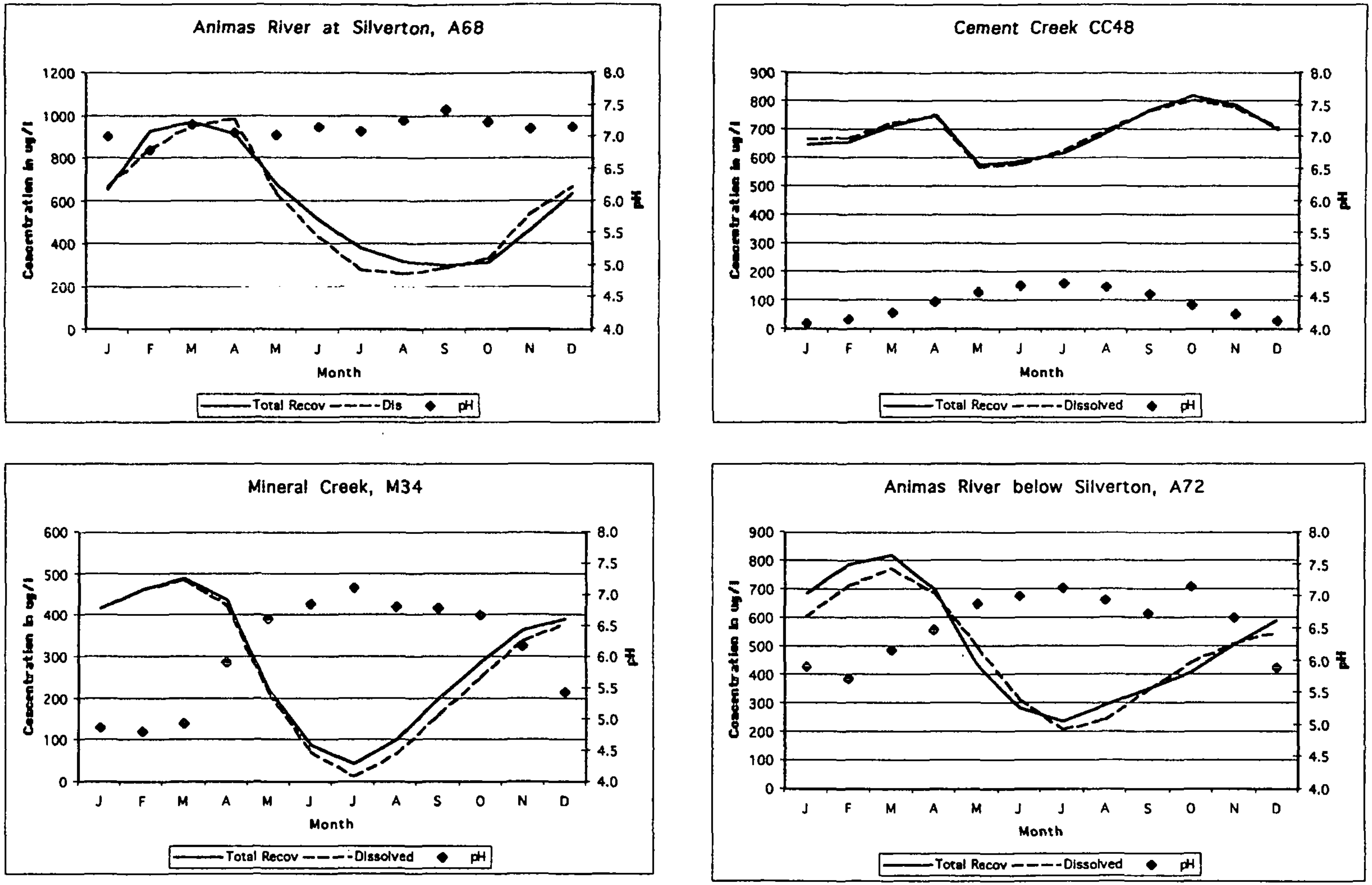


Figure 8.17 Comparison of total recoverable and dissolved zinc concentrations and the cyclical variation of pH at stream gages in the upper Animas Basin.

Groundwater

The contribution of solutes from groundwater may include both natural and human-induced components. Underground mine works that intersect faults and fractures, may convert groundwater contribution to an adit source. The SGC consent decree recognized that filling the Sunnyside mine with water could cause a re-emergence of solutes from ground water as the mine workings, faults and fractures filled with water. It has also been hypothesized that underground works have changed ground water hydrology, and the potential exists for metals to emerge as groundwater rather than adit.

Sources from groundwater, for the most part, were estimated as un-sampled flow. For example, a large increase in load measured between two points with no visible surface inflow was attributed to groundwater. At some locations it was possible to conclude that the un-sampled flow was natural because mining activity was minimal in the area. In other cases there was uncertainty as to the presence of sub-surface mining activity or leaching from waste material, thus no conclusion as to whether the solutes were from a natural or human-induced source could be made. The most significant observation is that contributions of solutes from the groundwater pathway are specific to each metal and to each of the three sub-basins.

The contribution of groundwater to solute concentration at A68, CC48, and M34 are shown in Figures 8.18 to 8.20. Groundwater accounts for nearly all of the base flow concentration of Al at A68, Figure 8.18. The concentrations of Al and Fe, however are low and owing to river pH above 6.0, are insignificant as sources of dissolved Al and Fe to down stream segments.

Glacial and alluvial sediment deposits fill the Animas valley between Eureka and the canyon south of Silverton, creating a potentially large ground water reservoir. Ore mills between Eureka and Silverton supplied huge quantities of tailings that were stored on the floodplain and terraces. Vincent and others (1999) estimated that near Eureka the fine fraction of streambed and floodplain sediments deposited after 1900 is composed of two-thirds mill tailings. Tracer studies by the Paschke and others (2000) concluded that most of the Zn loading to the Animas River between Eureka and Silverton was from ground water entering the river near sites containing mill tailings. Surface sources of metals from tributaries or adits in the reach are minor. Moreover, the concentration of Cd, Cu, Mn, and Zn increases earlier in the year at A68 than at CC48 or M34. The potential volume of water stored in the valley fill makes it difficult to make a sharp distinction between the groundwater and seasonal runoff components as the valley floor is subject to throughflow and saturated overland flow. Mill tailings scattered throughout the alluvium makes it difficult to be certain of the portion which may be natural and the portion that may be human-induced. A tracer dilution study by the USGS (Paschke and others, 2000) in August 1998 found the largest increases in Cu, Mn, and Zn loads were from groundwater between Howardsville and Silverton. This study concluded that "The influence of ground water discharge was particularly evident downstream from Blair Gulch. . ." Paschke and others (2000) found the largest increases in loads downstream from tailings near the Mayflower Mill, below Blair Gulch, below Howardsville and below tailings near the Lackawanna Mill.

Groundwater appears to be the source of most of the Al, Cu, Fe, and Zn in Cement Creek during base flow, Figure 8.19. Since SGC began treatment of all water in Cement Creek above the AT in late 1996, and it is assumed that treatment will end, concentrations shown in Figure 8.19 are for the pre-consent decree period. Treatment at the AT has lowered the Zn concentration by more than 200 ug/l during the winter. The reduction comes from both adits and natural groundwater. Between the AT and CC48 stations, relatively low concentrations of Al, Fe, and Zn measured from adits show they are a small proportion of those metals at CC48 during base flow. This suggests that most of these metals are from groundwater, minimally affected by mining. Over half of the Cu measured at CC48 is from groundwater during base flow. Groundwater accounts for a minor percentage of Al, Cu, Fe, and Zn concentration in Cement Creek during the runoff months.

Tracer-injection studies of Cement Creek by the USGS in September 1997 found that only about half of the Zn load was from identifiable tributary and mine sources (Kimball and others, 2000). The difference is attributed to loads contributed from un-sampled flow. Kimball identified two discrete reaches of Cement Creek, an iron bog below Prospect Gulch and a bog lower in Cement Creek where the increased Zn load corresponded to areas containing substantial fracture patterns, but no mining activity. A second source of subsurface inflow measured by Kimball in Cement Creek was in areas with large alluvial fans, such as those found at the bottom of Prospect, Minnesota, and Ohio Gulches (Kimball and others, 2000). Mines and waste rock are found in all three drainages, thus the contribution of Zn may be from water affected by mining and mined sources that reaches the stream as throughflow in the large alluvial fans near their bases.

Investigations of Mineral Creek (Yager and others, 2000) identified large quantities of Al and Fe in springs from areas that are not affected or only minimally affected by mining. Figure 8.20 shows that nearly all of the Al and most of the Fe in Mineral Creek at M34 is from groundwater year round. Most of the Al and Fe in Mineral Creek are from the Middle Fork of Mineral Creek. A tributary to the Middle Fork, nicknamed "Red Trib" (M18) is the largest source of Al and a major source of Fe in Mineral Creek. This area has not been impacted by mining. The Paradise Portal, a short distance upstream from the "Red Trib," is a second source of Al and Fe to Mineral Creek. This is a shallow portal, possibly abandoned when an underground fracture or fault containing a large volume of water, was encountered. The metals from this source quite possibly were naturally present since the collapsed portal excludes oxygen, a necessary element for AMD. Springs emanating from other shallow prospects, such as the Ferrocrete and Imogene mines, in the Mineral Creek watershed, are large sources of Al and Fe and are similar to the Paradise adit. In contrast to the large percentage of Al and Fe that are from groundwater, Figure 8.20, a relatively small proportion of the Cu and Zn in Mineral Creek are attributed to groundwater.

Shallow wells, driven into in the gravel in and around Silverton provide an overview of the Animas, Cement and Mineral Creek ground water flow regimes. Water from these wells showed varying concentrations of Cd, Cu, Pb, Mn, and Zn. The highest concentrations of Mn and Zn, 66,000 and 7000 ug/l respectively, were found at the Silverton campground near the north end of town. The well at the Silverton campground is upstream from A68, and groundwater from this area probably has an effect on the level of metals in surface water measured at A68 and A72. One well near the wastewater treatment plant at the south end of town, had 385 ug/l average Zn concentration.

Table 8.5 Comparison of loads of individual metals from non-permitted adits in the upper Animas basin to loads at the gages during base flow.

			Low flow load measured from adits in pounds per day					
		Adit flow (cfs)	Al	Cd	Cu	Fe	Mn	Zn
Animas	A68	5.3	9	0.10	1	42	44	24
Cement	CC48	3.2	12	0.07	1	135	39	14
Mineral	M34	6.1	141	0.32	29	750	65	94
	Gage	Flow(cfs)	Average total load at the gages during February					
Animas	A68	28	31	0.30	4	49	334	136
Cement	CC48	14	451	0.10	3	1025	135	67
Mineral	M34	22	521	0.10	7	679	64	64
		% of Flow	Percent of the total base flow load from adits					
Animas	A68	19%	30%	32%	20%	86%	13%	18%
Cement	CC48	23%	3%	70%	36%	13%	29%	21%
Mineral	M34	28%	27%	318%	413%	110%	101%	146%

Adits

Water quality investigations by the ARSG, CDPHE, USGS, USFS, BLM, SGC, and other private interests, sampled drainage from 173 adits and prospects within the Upper Animas Basin for the target metals. Other mine openings were inspected at different times, but they were not discharging. Most mines were sampled at both high and low flow periods. A few mines with winter access were sampled year-a-round. Sampling revealed that the discharge from most adits is relatively constant throughout the year. High flow is seldom twice that of low flow.

The proportion of metals from adits to the down stream concentration is largest during base flow. Discharge from adits has very little affect on the concentration of most metals observed at the three gages during the runoff months of May through October, Figures 8.18 to 8.20. The average load from adits of each of the six metals in the Animas River above Silverton, Cement Creek and Mineral Creek are shown in Table 8.5. February is used because it is the lowest flow month when seasonal runoff is most likely to be zero. The loads in Table 8.5 probably over estimate the loads from adits in February because most low flow samples were from September or October and it's assumed the load remained constant into the winter. Table 8.5 also assumes that all metals from adits reaches the gage without any attenuation. The numbers for Cd, Cu, Fe, and Zn loads (and possibly Mn) from adits in Mineral Creek, suggest that either the loads from adits aren't constant, or there is attenuation.

Several adits in the Upper Animas Basin have already been sealed or the discharge is being treated. The AT, located on Cement Creek near Gladstone, historically was a large source of metals. Drainage from the AT has been treated at varying levels since the 1960's. Removal of the largest quantities of metals began 1989. A bulkhead, placed in the tunnel in late 1996, partially sealed the discharge. Complete closure of the AT is scheduled in accordance with the Sunnyside Consent decree. Several other adits, including the Terry Tunnel (1996), Lower

Ransome adit (1998) on Eureka Creek, and the Sunbank (1993) and Gold Prince (1997) adits near the Animas headwaters have been sealed.

Adits account for eighteen percent of the Zn concentration in the Animas at Silverton (A68) during base flow, but are not a significant part of the total concentration at other times, Figure 8.18.

Cu and Zn from adits in Cement Creek are significant through base flow, but not during runoff. Sampling shows that a remarkably small percentage of the Al and Fe in Cement Creek comes from adits, Figure 8.19. However, two of the larger draining adits, the Grand Mogul and Mogul are above the AT, thus between 1996 and 1999 the AT plant removed metals from these mines during base flow. Figure 8.19 is based on data collected after the consent decree was implemented. Treatment of Cement Creek, which removed metals from both adits and ground water above the AT, between 1996 and 1999 lowered the average concentration of Cu and Zn at CC48 by 15 and 212 ug/l, respectively.

Adits are responsible for the largest percentage of the Cd, Cu, and Zn in Mineral Creek most of the year. More than half of the Cd, Cu, and Zn are from two adits in the Red Mountain Pass area. The Paradise adit, on the Middle Fork of Mineral Creek and upstream of the "Red tributary," contributes over half of the Fe in Mineral Creek during the winter months. The data show that adits are a minor source of Al in Mineral Creek, Figure 8.20.

Seasonal Runoff

Seasonal runoff includes overland flow and throughflow. It is identified by a decrease in solute concentration, accompanied by a steep increase in load and flow. Seasonal runoff that contacts incompletely weathered pyrite such as found in alluvial fans, eroding headcuts, waste rock, or mill tailings are sources of acid and metals. Metal loading from seasonal runoff may be attributed to natural, mine-related, and other human-related factors such as overgrazing, road cuts, or any other activity that accelerates erosion within the acid surface environment.

Many factors determine the amount of metals that may be contributed to streams from mine waste in the Upper Animas Basin. Mine waste includes dump material deposited near mine-workings and mill-tailings. It is assumed that all metal loading from mine waste is contributed to the streams as part of both throughflow and overland flow.

One factor is location of mine waste in relation to surface and groundwater. The potential for metal loading from mine waste is greatest in the spring during snowmelt and in late summer during thunderstorms. The load of Al, Cd, Cu, Fe, and Zn from Prospect Gulch in the Cement Creek watershed was observed to increase one or more orders of magnitude during September storm runoff conditions. The largest immediate increases in loads corresponded to areas where waste-rock dumps were in close proximity to the stream (Wirt and others, 2000).

An intensive investigation of the Mayday mine waste pile in the Cement Creek watershed (Stanton, 2000) found the highest concentrations of Cu, Pb, and Zn were associated with secondary minerals at 2-3 meters depth. Large numbers of iron- and sulfur-oxidizing microbes, and secondary Fe minerals were found at depth in the waste dump indicating that metals are mobile in the sub-surface. Because water is available on a sporadic basis at the Mayday dump—and many other dumps in the basin—rates of weathering reactions and mineral dissolution are sporadic as well (Stanton, 2000).

Composition and mineralogy of the host rock is another factor. Waste rock from mine workings driven through non-sulfide bearing minerals, has little acid producing potential. Workings driven on vein are major sources of acid rock drainage. Both types of material may be present in the same dump.

Mill tailings have a higher acid generating capability because finely ground rock exposes more surface area to oxidation. Moreover, rock transported to the mills generally contained major ore bearing minerals such as pyrite, sphalerite, galena, and enargite which have the richest metal content and the highest acid generating potential. Early mill technology concentrated on recovery of gold and silver, which often left large quantities of the base metals in the tailings.

Mill tailings have been relocated and consolidated to several areas along the Animas River, mostly within segment 3a. Mill tailings at the Mayflower Mill (Ponds 1-4) have been capped and revegetated in accordance with SGC's mine reclamation plan. Mill tailings, from the South Fork of Cement Creek, were relocated to tailings pond #4 between 1990 and 1992. Data collected by SGC from the South Fork of Cement Creek (CC17) shows that relocation of this pile decreased the dissolved Al and Fe concentration in South Cement Creek. SGC removed over 100,000 cubic yards of tailings from the Eureka floodplain in 1996 and relocated some of the historic mill tailings from Howardsville to tailings pond # 4 near Silverton in 1997.

Waste rock from two sites near the top of Red Mountain Pass have been partially or completely remediated. SGC covered, amended and vegetated the Longfellow dump and relocated the Kohler waste rock pile to the Mayflower Mill #4 pond in 1996-97. ARSG, with the assistance of a 319 non-point source grant, is currently relocating the waste rock pile at nearby Carbon Lakes to Pond #4.

ARSG participants leach tested composite samples of the upper six inches of surface waste of 157 mine waste piles. Details of investigations of mine waste contributions are found in Chapter X and Herron and others (1997, 1998, 1999, and 2000). In addition to the leach tests, surface area estimates of all mine waste areas larger than 100 square meters above A72 have been made from aerial orthophotographs. Surface area estimates indicate that mine wastes covers about 0.15 percent of the area above A72.

The contribution of metal load from the piles can be estimated by applying annual throughflow and overland flow estimates to the surface areas of the waste rock piles and by using the results of the leach tests. Throughflow and overland flow was computed by comparing the annual discharge from the Basin during 1996-99 to the acreage of the drainage (29 inches yearly). The annual metal load from waste rock expressed in pounds per year and as a percentage of seasonal runoff is summarized in Table 8.6.

Table 8.6 Comparison of loads of individual metals from mine waste rock in the Upper Animas Basin to total seasonal runoff loads at the gages. Loads are in pounds per year.

Waste Pile	Area (ac)	Al	Cd	Cu	Fe	Mn	Zn
Animas	79.3	895	33	506	2,902	4,386	5,438
Cement	26.6	2,432	86	1,611	39,479	1	14,233
Mineral	28.5	2,437	19	296	32,548	1,753	2,102
Watershed	Area (ac)	Metal Loads from Seasonal Runoff in Pounds per Year					
Animas (A68)	45,184	35,604	169	2,703	100,163	141,264	91,242
Cement (CC48)	12,864	85,338	128	4,456	646,383	18,828	42,273
Mineral (M34)	33,536	64,571	49	1,348	125,533	8,815	19,672
	% of Area	Percent of Seasonal Runoff from Dumps					
Animas	0.176%	2.5%	19.6%	18.7%	2.9%	3.1%	6.0%
Cement	0.206%	2.8%	67.1%	36.2%	6.1%	0.0%	33.7%
Mineral	0.085%	3.8%	38.1%	21.9%	25.9%	19.9%	10.7%

The basins largest tailings repositories are currently the permitted sites at the Howardsville and Mayflower Mills east of Silverton. Since these sites are permitted and already have runoff controls or have been reclaimed, they were excluded from calculations for total waste rock contributions.

Metals from waste rock, distributed across the seasonal runoff period as a percentage of the total seasonal runoff and total metal concentration, are shown in Figures 8.18 to 8.20. Zn is the predominate solute from seasonal runoff in the Animas River above Silverton (Figure 8.18). Analysis of the dissolved concentration data in segment 3a indicates that most of the Zn from seasonal runoff enters the river between Arrastra Gulch and the gage at A68. Most of the Cd, Cu, and Mn, not shown, are attributed to seasonal runoff in the same reach as the Zn.

Seasonal loading is most apparent in Cement Creek. Unlike other metals found in the streams in the Basin, the highest concentration of Cu occurs in conjunction with high streamflow (Figure 8.19). Seasonal runoff also produces more Al, Fe, and Zn in Cement Creek than in the Upper Animas or Mineral Creek basins.

Seasonal runoff as a source of solutes in Mineral Creek is the least of the three sub-basins. A very small proportion of the Al and Fe in Mineral Creek is from seasonal runoff (Figure 8.20).

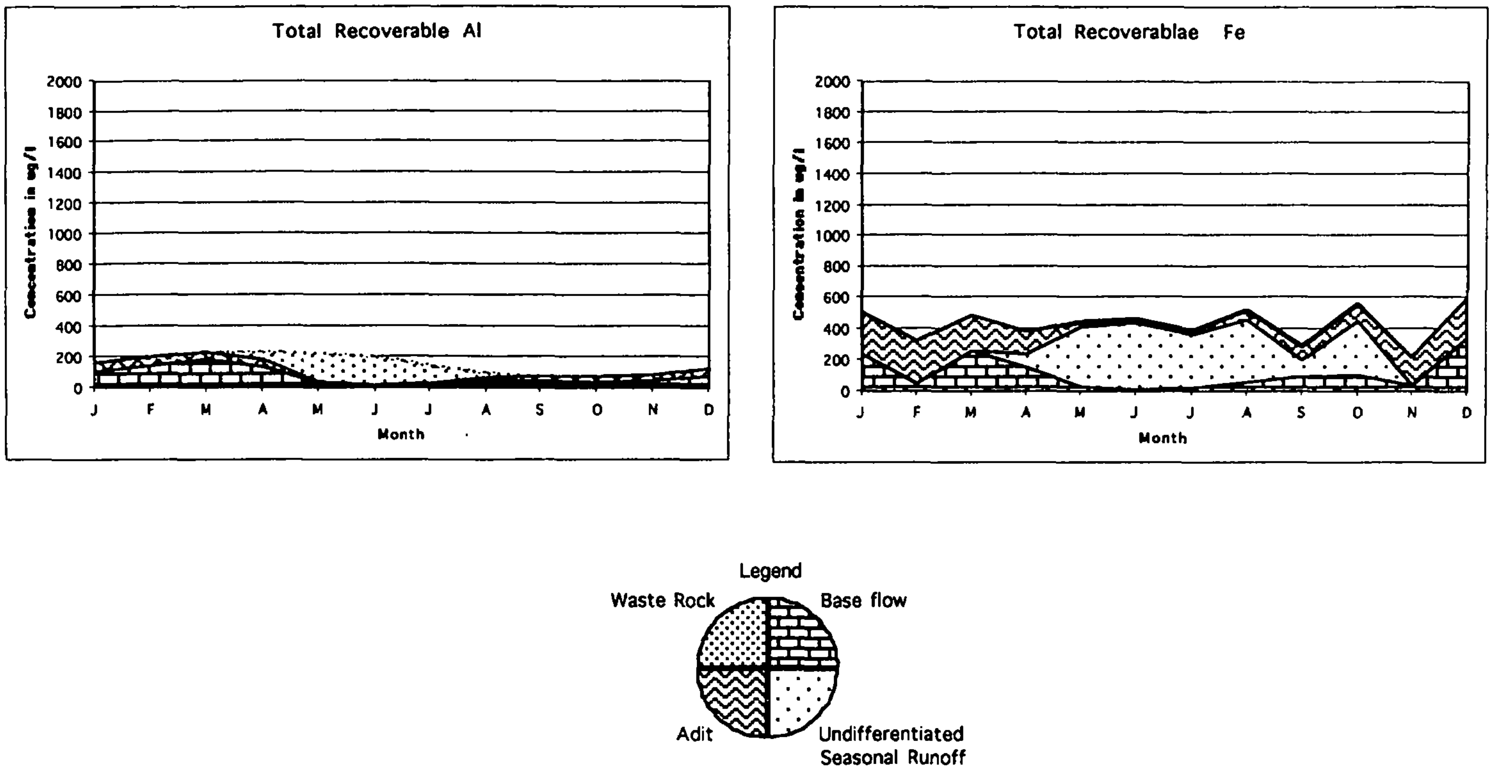


Figure 8.18a Seasonal, flow-based sources of total recoverable aluminum and iron to A68, the Animas River at Silverton, estimated from the water quality regression model. Stream flow is the average monthly flow at A68, 1993 to 1999. Calculated values are for the 15th day of each month.

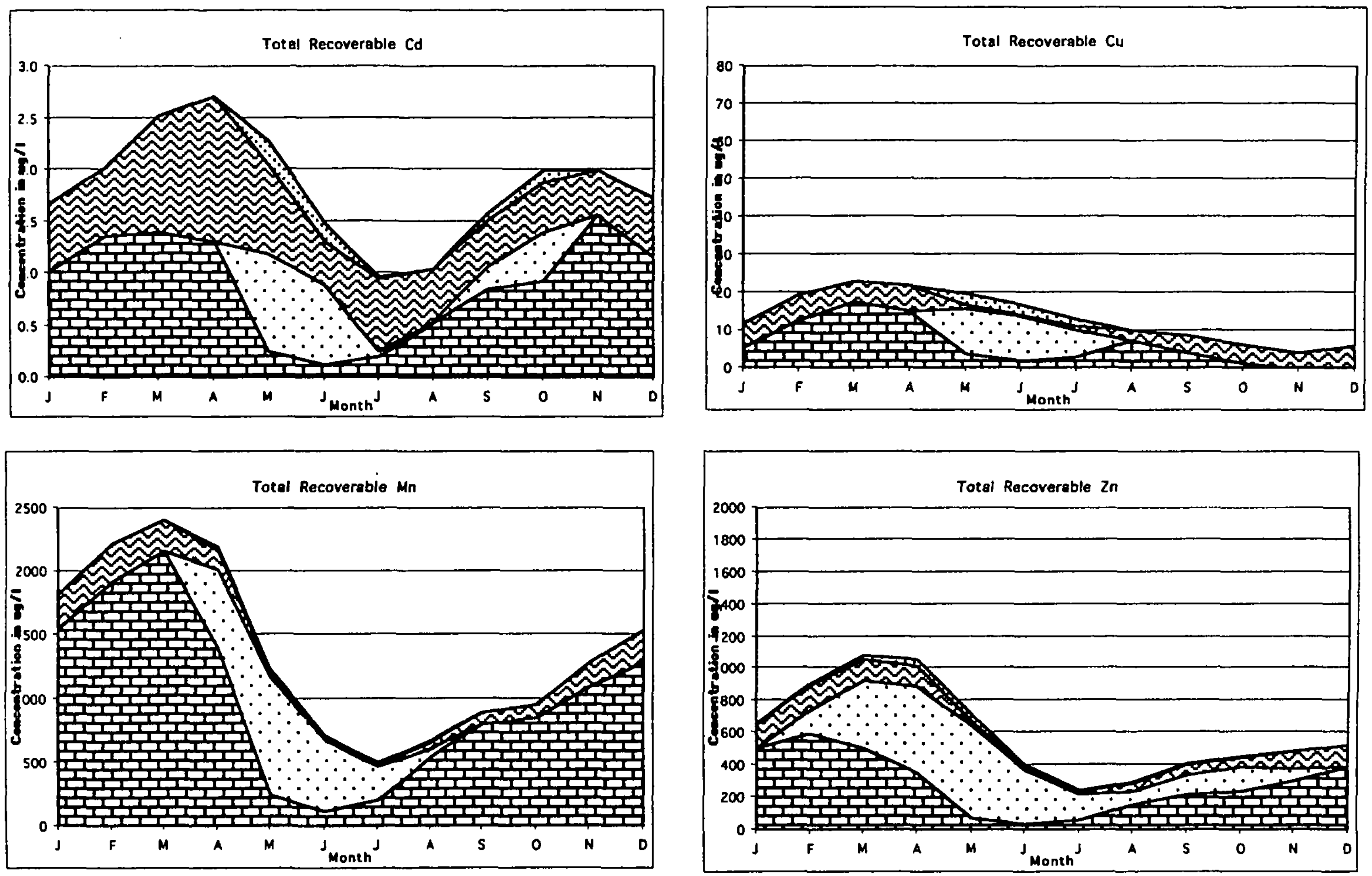


Figure 8.18b Seasonal, flow-based sources of total recoverable cadmium, copper, manganese and zinc to A68, the Animas River at Silverton, estimated from the water quality regression model. Stream flow is the average monthly flow at A68, 1993 to 1999. Calculated values are for the 15th day of each month.

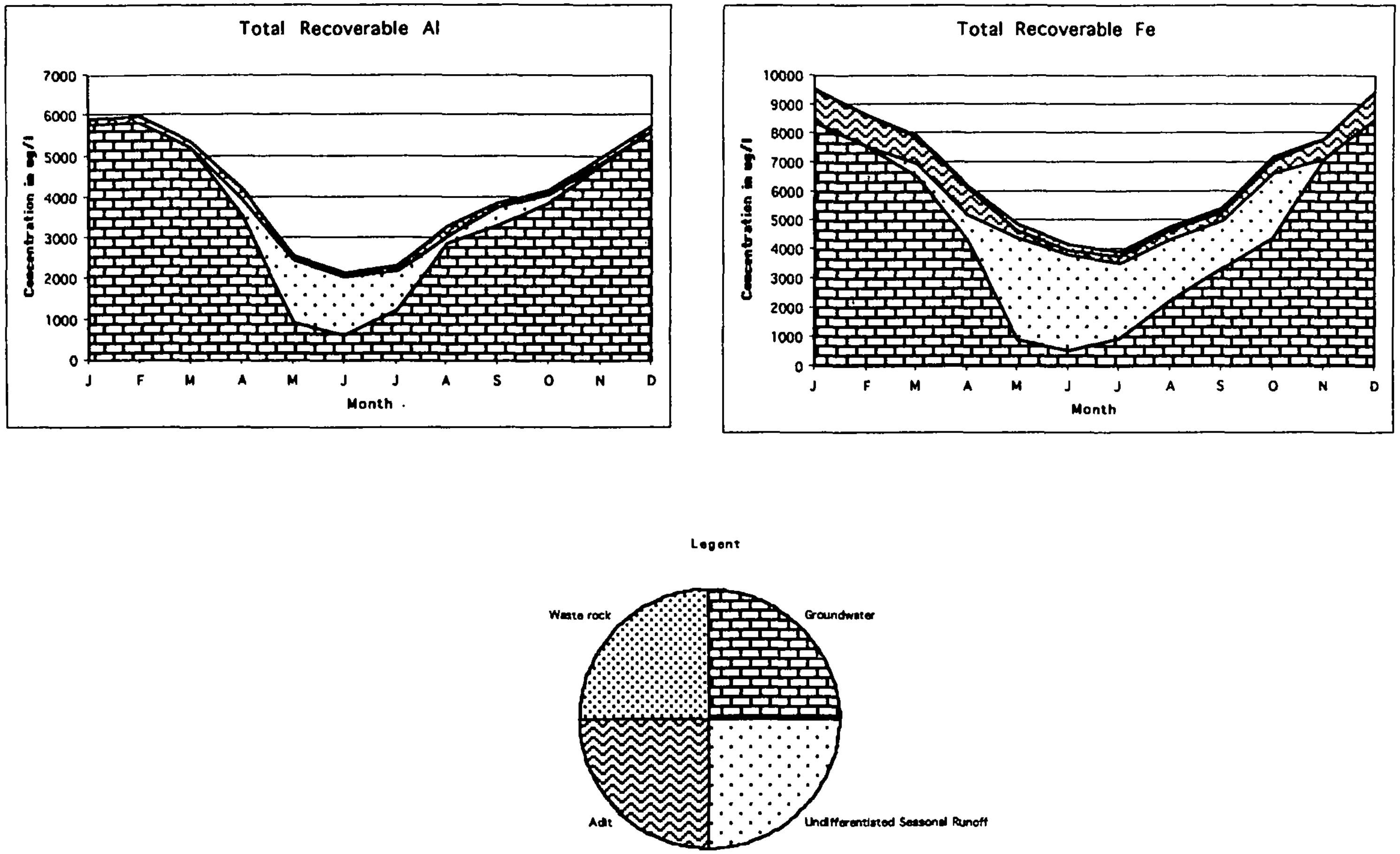


Figure 8.19a Seasonal, flow-based sources of total recoverable aluminum and iron to CC48, Cement Creek at Silverton, estimated from the water quality regression model. Stream flow is the average monthly flow at CC48, 1993 to 1999. Calculated values are for the 15th day of each month.

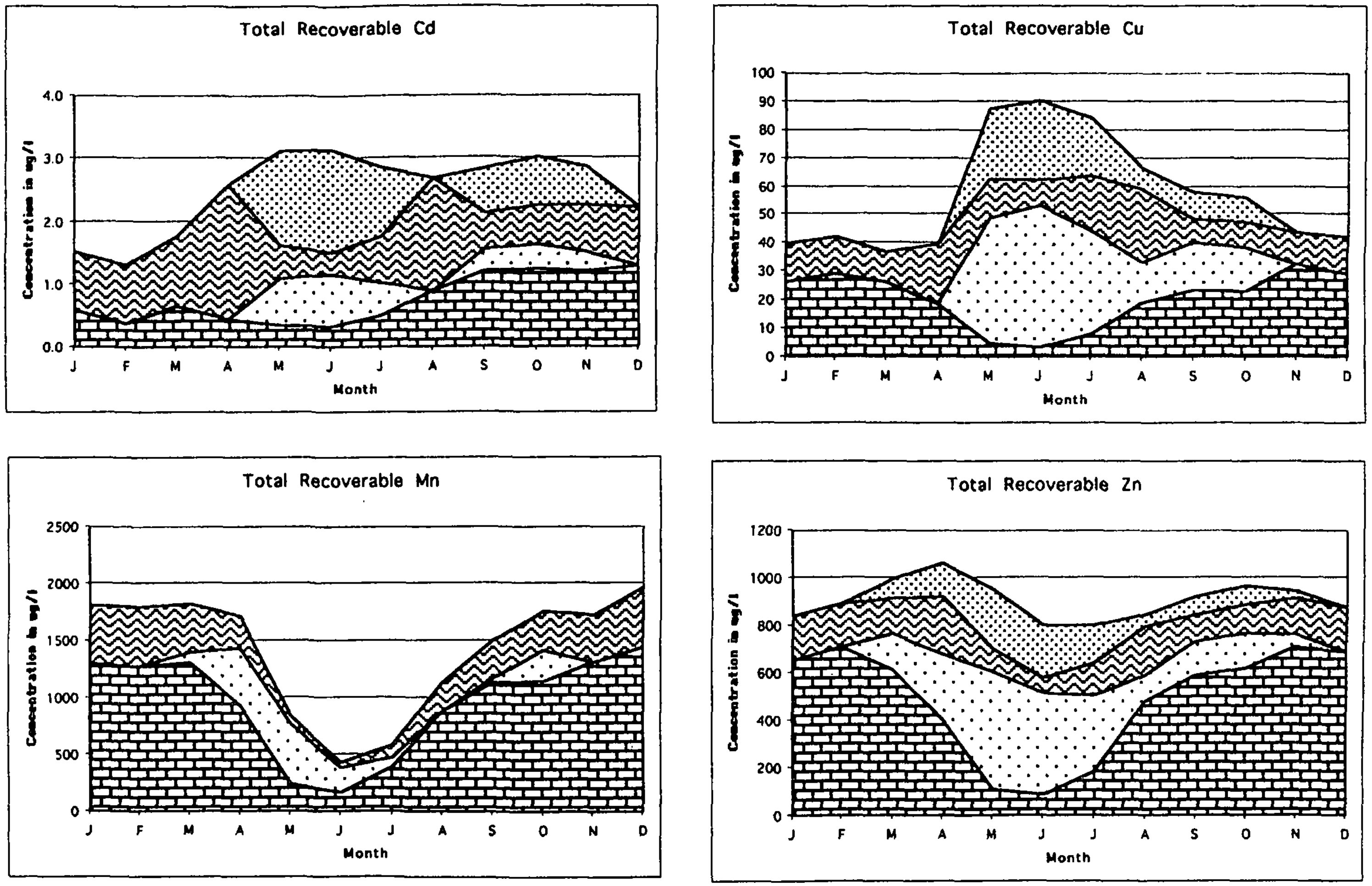


Figure 8.19b Seasonal, flow-based sources of total recoverable cadmium, copper, manganese, and zinc to CC48, Cement Creek at Silverton, estimated from the water quality regression model. Stream flow is the average monthly flow at CC48, 1993 to 1999. Calculated values are for the 15th day of each month.

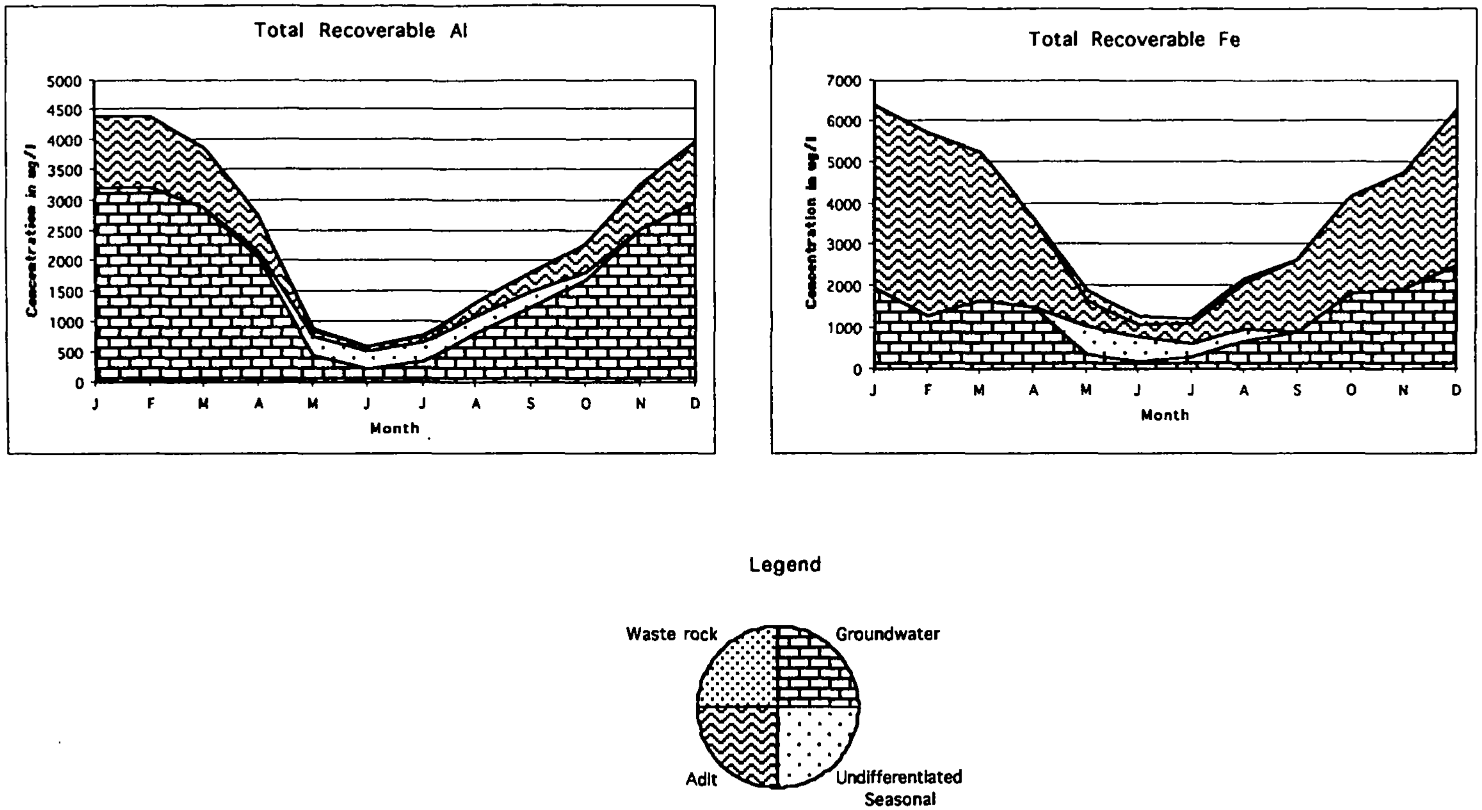


Figure 8.20a Seasonal, flow-based sources of total recoverable aluminum and iron to Mineral Creek near Silverton, estimated from the water quality regression model. Stream flow is the average monthly flow at M34, 1993 to 1999. Calculated values are for the 15th day of each month.

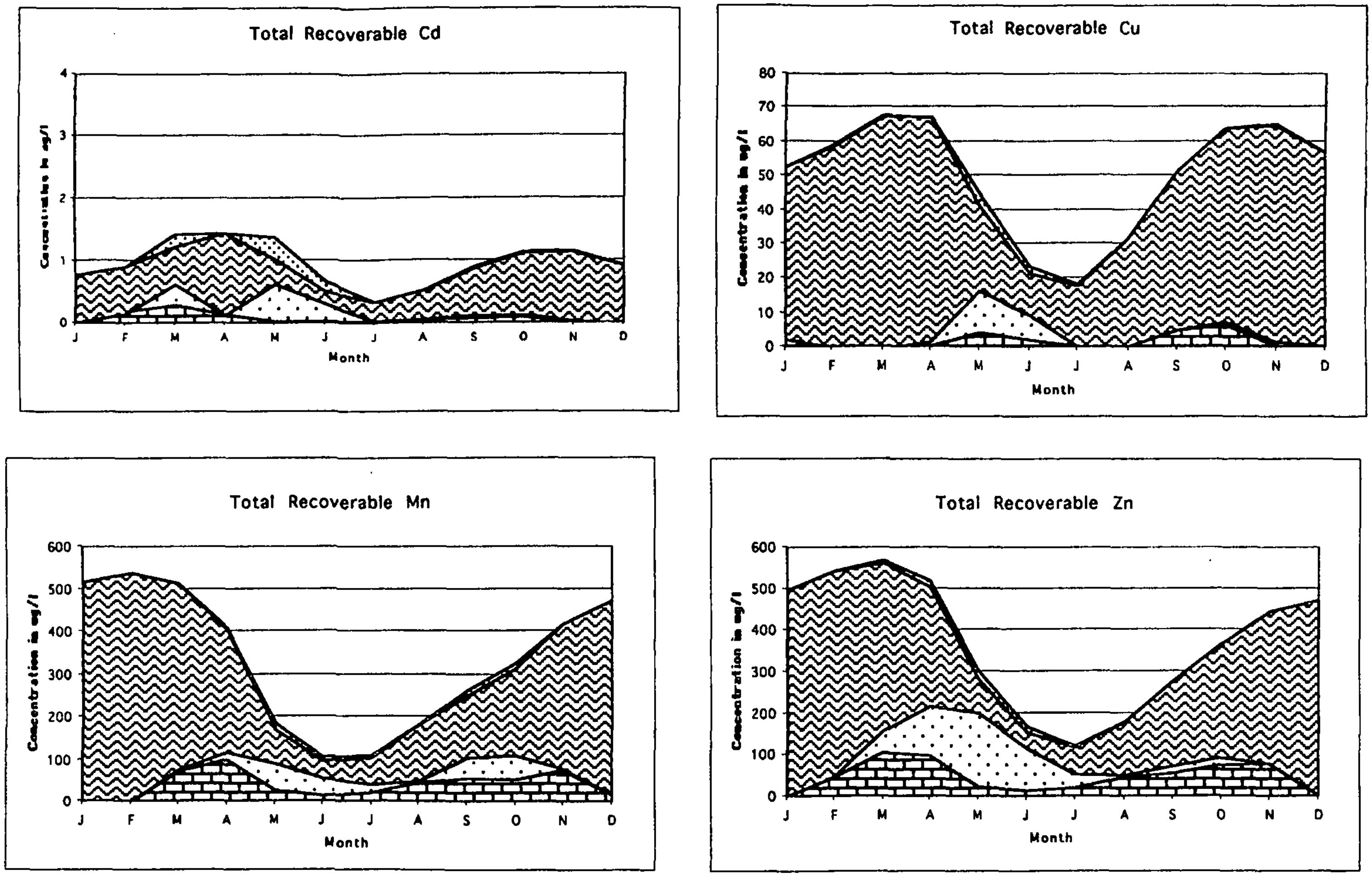


Figure 8.20b Seasonal, flow-based sources of total recoverable cadmium, copper, manganese, and zinc to Mineral Creek near Silverton, estimated from the water quality regression model. Stream flow is the average monthly flow at M34, 1993 to 1999. Calculated values are for the 15th day of each month.

Combined Effects in the Animas River below Silverton

One of the goals of the UAA is to estimate the water quality that could be achievable in the Animas River below Mineral Creek if "reversible" sources of metal loading were remediated. Sources of metals measured at A72 are from the three sub-basins discussed above. Each of the sub-basins contributes a differing amount of stream flow based on the area of its watershed. The concentrations of the different metals and their sources, groundwater, adits, and seasonal runoff are different for each of the sub-basins. Figure 8.20 combines the solutes and their sources to show their combined effect at A72, the Animas River below Silverton.

Nearly all of the total recoverable Al measured at A72 can be attributed to groundwater sources. Concentrations are highest in the winter when stream flow is the least. Figure 8.14 shows that most of the Al is in colloidal form by the time it reaches A72. However, the concentration of dissolved Al exceeds chronic toxicity criteria (87 ug/l) for trout species for over four months of the annual cycle.

Groundwater, adits, and seasonal runoff affect the total recoverable Fe concentration at A72. The Fe concentration is highest during winter low flow with about two-thirds coming from groundwater. Groundwater sources of total recoverable Fe exceed aquatic life criteria (1000 ug/l) for over nine months of the year. Controlling sources of Fe from adits and seasonal runoff could improve water quality, but TVS criteria could not be met most of the time.

Groundwater, adits and seasonal runoff are all sources of total recoverable Zn at A72. Total recoverable and dissolved Zn concentrations at A72 are nearly identical (See Figure 8.17), therefore Figure 8.21 also represents sources of dissolved Zn. Zn levels could be substantially reduced if sources from adits and seasonal runoff were controlled. Owing to winter contributions from ground water however, it is unlikely that acute and chronic TVS criteria can be met at A72 during the months of October through April.

Figure 8.21 indicates that more of the total recoverable Cu at A72 is from adits and seasonal runoff than from ground water. Dissolved Cu has been suggested as a possible limiting factor for brook trout (Besser, 2000). Controlling sources of Cu from adits or seasonal runoff should enable the segment to meet this aquatic life criteria.

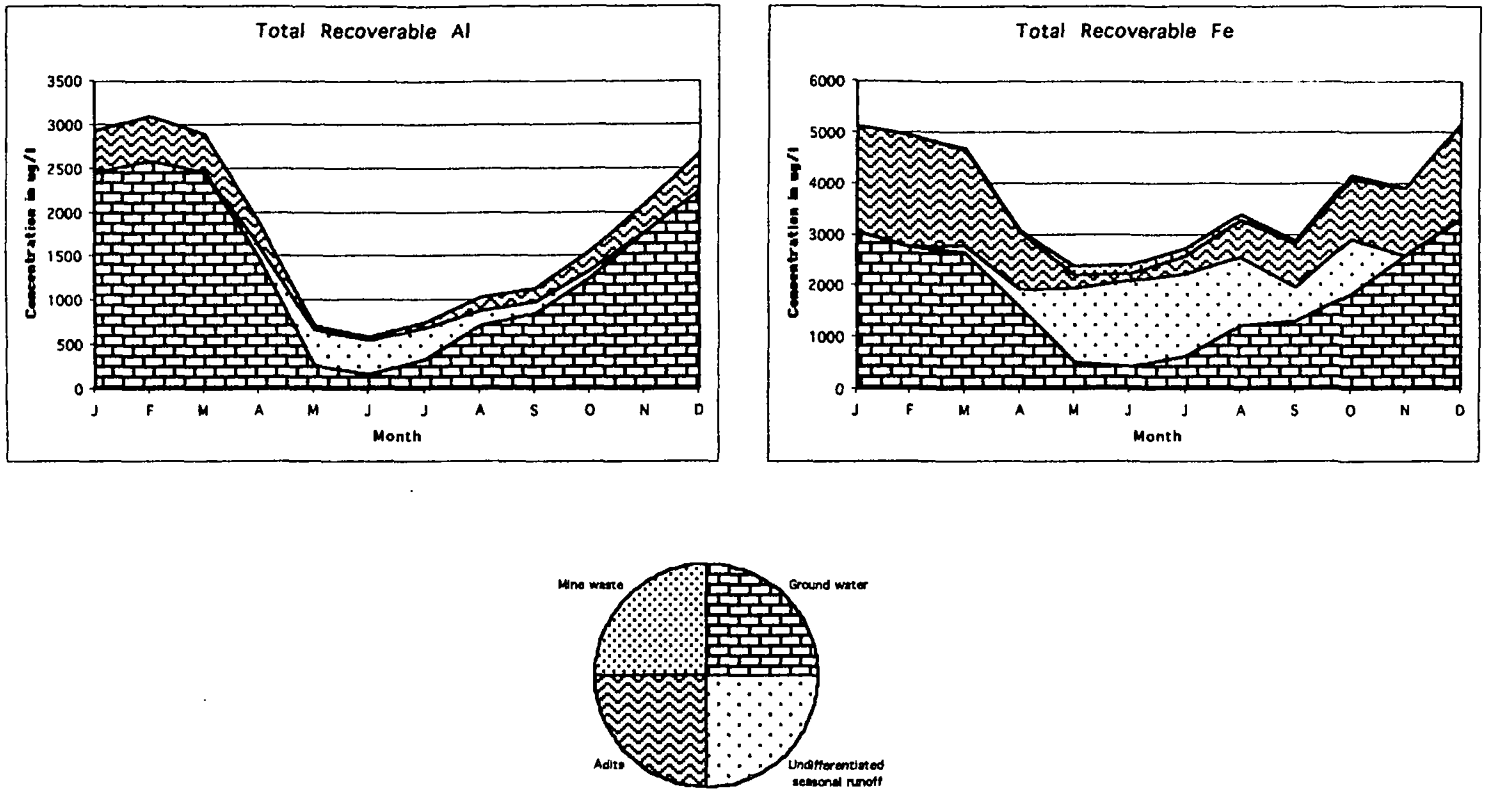


Figure 8.21a Seasonal, flow-based sources of total recoverable aluminum and iron to the Animas River below Silverton, estimated from the water quality regression model. Stream flow is the average monthly flow at A72, 1993 to 1999. Calculated values are for the 15th day of each month.

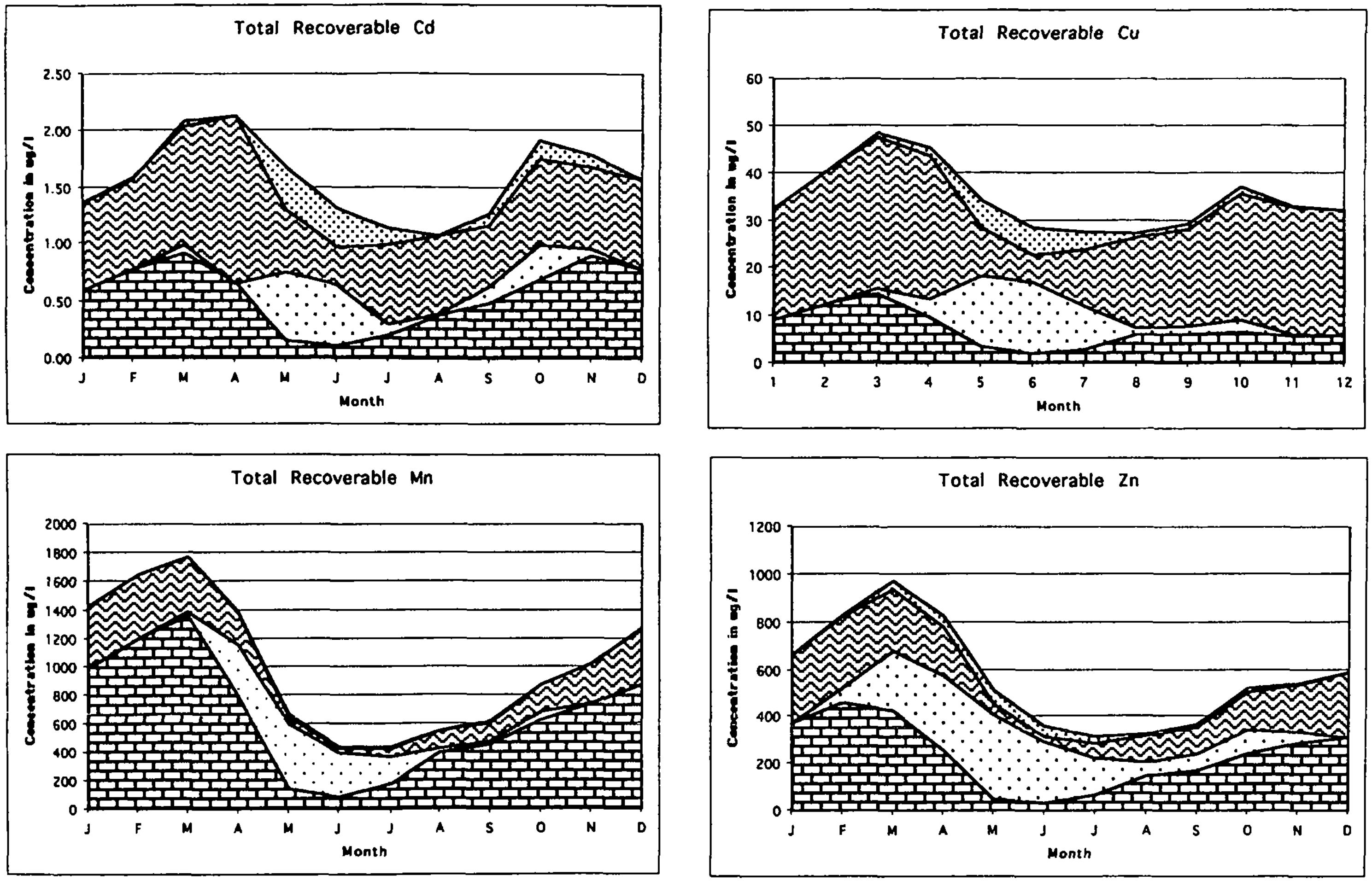


Figure 8.21b Seasonal, flow-based sources of total recoverable cadmium, copper, manganese and zinc to the Animas River below Silverton, estimated from the water quality regression model. Stream flow is the average monthly flow at A72, 1993 to 1999. Calculated values are for the 15th day of each month.

Other Human Impacts:

Other human activities in the basin have the potential to impact water quality, especially within the acid-sulfate and quartz-sericite-pyrite regions of Cement and Mineral Creek watersheds. Exposure of fresh sulfide minerals to air, water, and microbial action are especially critical because it could increase the production of acid water and higher metal loads in nearby streams. Roads used to reach the mine sites and for recreation use are potential sources of metals loading. Alpine sections of the headwaters of the Animas, Mineral, and Cement Creeks have grazing allotments for sheep. Accelerated erosion, caused by improper grazing, is one mechanism that could lead to additional acid water production in selected areas.

The acidity of the precipitation can also be an influential factor by helping to create conditions favorable to acid rock drainage. Bacteria necessary for this catalytic reaction, which then releases even more acid into the environment, begins to flourish if the fluid acidity is below a pH of 5.5. The average pH of precipitation at Molas Pass (five miles south of Silverton) from 1986 through 1993 was recorded by the National Atmospheric Depositional Program as 5.0. This low pH, coupled with low available alkalinity though out the caldera could add to the natural and human-induced acid drainage.

Silverton discharges about 0.2 cfs of municipal wastewater to the Animas River above Mineral Creek. ARSG sampled a major sewer main at two locations and the inflow into the treatment facility. Cadmium, copper, lead, manganese, and zinc were all found at concentrations lower than concentrations found in the river. The wastewater treatment plant is not a significant source of metals.

Cold, swift water of the Animas minimizes the potential for DO problems. Similarly, low water temperature and low pH in the Animas also minimizes any potential for unionized ammonia. Fecal coliform from the wastewater plant could affect recreational use of the river, however recreational use is confined to high flow periods when dilution is maximal.

REFERENCES

Besser, John. 2000. USGS. Personal communications; Results of biotoxicity study on brook trout using Animas River water. Results to be published winter of 2000-01.

Cady, T., B. Horn, R. Owen, B. Simons, B. Stover. 1996. *Reconnaissance of the Animas Canyon* (August 16-18, 1995).

Colorado Water Quality Control Commission. 1999. "The Basic Standards and Methodologies for Surface Water" 5CCR 1002-31. CDPHE.

Farrell, Camille M. S. 1997. *Comprehensive Analytical Results Report Cement Creek watershed, San Juan County, Colorado.* Colorado Division of Hazardous Materials and Waste Management; CDPHE.

Farrell, Camille M. S. 1997. *Site inspection sampling activities report Upper Animas watershed, San Juan County, Colorado.* Colorado Division of Hazardous Materials and Waste Management; CDPHE.

Helsel, D. R. and Hirsch, R. M. 1995. *Statistical Methods in Water Resources.* Elsevier, Amsterdam.

Herron, J., Stover, B., Krabacher, P., and Bucknam, D. 1997. *Mineral Creek feasibility investigations report, upper Animas River basin.* Colorado Division of Minerals and Geology.

Herron, J., Stover, B., Krabacher, P., 1998. *Cement Creek reclamation feasibility report, upper Animas basin.* Colorado Division of Minerals and Geology.

Herron, J., Stover, B., Krabacher, P., 1999. *Reclamation feasibility report, Animas River above Eureka.* Colorado Division of Minerals and Geology.

Herron, J., Stover, B., Krabacher, P., 2000. *Reclamation feasibility report, Animas River below Eureka.* Colorado Division of Minerals and Geology.

Kimball, B. A., Runkel, R.L., Walton-Day, K., Bencala, K. E. 2000. *Assessment of metal loads in watersheds affected by acid mine drainage by using tracer injection and synoptic sampling: Cement Creek, Colorado, USA.* (in press).

Kimball, B. A., Schemel, L. S., Cox, M. J., and Gerner, L. J. 2000. *Loading and Chemical Reactions metals entering the Animas River between Silverton and Elk Park, San Juan County, Colorado.* (in press).

Kinball, B. A. 2000. Personal communication. U. S. Geological Survey.

Knighton, David. 1984. Fluvial Forms and Processes. Edward Arnold, Publisher.

McIntyre, Susan. 2000. Personal communication. CDPHE. WQCD.

Nordstrom, D. K., Alpers, C. N., Coston, J. A., Taylor, H. E., McCleskey, R. B., Ball, J. W., Ogle, S., Cotsifas, J. S. and Davis, J. A. 1999. *Geochemistry, toxicity and sorption properties of contaminated sediment and pore waters from two reservoirs receiving acid mine drainage.* U. S Geological Survey Water Resources Investigations Report 99-4018A.

Owen, J. R., 1997. *Water quality and sources of metal loading to the upper Animas River basin.* Colorado Department of Public Health and Environment, Water Quality Control Division.

Paschke. S.S., Kimball, B. A., and Runkel, R. L. 2000. *Quantification and simulation of metal loading to the upper Animas River, Eureka to Silverton, San Juan County, Colorado, September 1997 and August 1998.* (in press).

Perrino, Larry. 1999. Personal communication. Sunnyside Gold Corporation.

Schemel. L. E., Kimball, B. A., and Bencala, K. E. 1999. *Colloid formation and the transport of aluminum and iron in the Animas River near Silverton, Colorado. U. S* Geological Survey Water Resources Investigations Report 99-4018A.

Stanton, M. R. 2000. *The role of weathering in trace metal redistributions in the Mayday Mine dump near Silverton, Colorado.* U. S. Geological Survey Open-File Report 00-034.

Vincent, K. R, Church, S. E., and Fey, D. L. 1999. *Geomorphological context of metal-laden sediments in the Animas River floodplain, Colorado.* U. S Geological Survey Water Resources Investigations Report 99-4018A.

U. S. Geological Survey, 2000, *Interim report on the scientific investigations in the Animas River watershed, Colorado to facilitate remediation decisions by the U.S. Bureau of Land Management and the U.S. Forest Service*, March 29, 2000 Meeting, Denver, Colo., U.S. Geological Survey Open-File Report 00-245, 34 p.

Water Quality Control Division. 1994. Exhibit 3, Upper Animas Water Quality Classifications and Standards Proposal. Colorado Department of Public Health and Environment.

Wirt, L., Leib, K. J., Mast, M. A., and Evans, J. B. 2000. *Chemical-constituent loads during thunderstorm runoff in a high-altitude alpine stream affected by acid drainage.* U.S. Geological Survey Open-File Report 00-034.

Yager, D. B., Verplank, P. L., Bove, D. J., Wright, W. G., and Hageman, P. L. 2000. *Natural versus mining-related water quality degradation to tributaries draining Mount Moly, Silverton, Colo.* U. S. Geological Survey Open-File Report 00-034.

Appendices

Appendices to Chapter VIII are Microsoft WORD and EXCEL 97-98 files that contain the data and analyses used for the UAA. Following is a brief description of the files in the Appendices.

Appendix 8 A: Contains the water quality data collected from streams and adits by the USGS, WQCD, DMG, USFS, BLM, CDOW, and the ARSG from 1991 through September 30, 1999.

Cement Creek.xls
Mineral Creek.xls
Upper Animas.xls
Lower Animas.xls

Appendix 8 B: Contains spreadsheets used to calculate acute and chronic table value standards and the 85th percentile concentrations at selected main stem locations.

Ac/Ch TVS.xls
Arrastra.xls
PH.xls
Seg_2.xls
Seg_3a.xls
Seg_4a.xls
Seg_4b.xls
Seg_7.xls
Seg_8.xls
Seg_9b.xls

Appendix 8 C: Contains an MS WORD document, WQRM.doc, that describes the regression approach for the WQRM. Also contains the data, statistics, and regression equations for dissolved and total recoverable Al, Cd, Cu, Fe, Mn, and Zn at the four gaging stations used for the WQRM

Regression equations for dissolved metals

A68DREG.xls
A72DREG.xls
CC48DREG.xls
M34DREG.xls

Regression equations for total recoverable metals

A68TREG.xls
A72TREG.xls
CC48TREG.xls
M34TREG.xls

And the following worksheets showing the partitioning of total loads into groundwater, adits, waste rock, and undifferentiated seasonal runoff for each of the gaging stations:

A68_Sour.xls
A72_Sour.xls
CC48_Sour.xls
M34_Sour.xls